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LECTURES

ON THE

APPLICATIONS OF CHEMISTRY AND GEOLOGY

TO

AGRICULTURE.

"The profit of the earth is for all; the king himself is served by the field."—*Eccles.* v. 9.

BY JAS. F. W. JOHNSTON, M.A., F.R.SS.L.&E.
FELLOW OF THE GEOLOGICAL AND CHEMICAL SOCIETIES,
Honorary Member of the Royal Agricultural Society, Foreign Member of the Royal Swedish Academy of Agriculture, &c. &c.; Chemist to the Agricultural Chemistry Association of Scotland, and Reader in Chemistry and Mineralogy in the University of Durham.

WITH AN APPENDIX,
CONTAINING SUGGESTIONS FOR EXPERIMENTS IN PRACTICAL AGRICULTURE.

NEW YORK:
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161 BROADWAY.

1844.

TO THE

VENERABLE CHARLES THORP, D.D., F.R.S., &c., &c.,

ARCHDEACON OF DURHAM, AND WARDEN OF THE UNIVERSITY OF DURHAM.

MY DEAR SIR,—

I cannot more appropriately dedicate the following Lectures than to the head of the University with which I am officially connected, and within the walls of which the earlier Lectures were first delivered.

In publishing this Volume I am only endeavouring to follow out the enlightened intentions of yourself and the other Founders of the University of Durham, who have contributed so largely of their fortune and their influence for the promotion and diffusion of sound and useful learning. That you have so long and so successfully laboured to carry these intentions into effect, is another reason why I desire to dedicate my work especially to you.

I need scarcely add how much pleasure it affords me to embrace this public opportunity of testifying my own personal regard and esteem.

Believe me, my dear Sir,
With much respect,
Your obedient humble servant,
JAMES F. W. JOHNSTON.

Durham, 1*st June*, 1844.

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PREFACE.

THE First Part of the following Lectures was addressed to a Society* of practical agriculturists, most of whom possessed no knowledge whatever of scientific Chemistry or Geology. They commence, therefore, with the discussion of those elementary principles which are necessary to a proper understanding of each branch of the subject. Every thing in such Lectures, which is not—or may not be—easily understood by those to whom they are addressed, is worse than useless. It has been my wish, therefore, to employ no scientific terms, and to refer to no philosophical principles, which I have not previously explained.

To many who may take up the latter portions of the work, some points may appear obscure or difficult to be fully understood; such persons will, I hope, do me the justice to begin at the beginning, and to blame the Author only when that which is necessary to the understanding of the later is not to be found in the earlier Lectures.

For the sake of clearness, I have, in the following pages, divided the subject into *four* Parts—the study of each preceding Part preparing the way for a complete understanding of those which follow. Thus, Part I. is devoted to the *organic elements* and parts of plants, the nature and sources of these elements, and to an explanation of the mode in which they become converted into the substance of plants;—Part II., to the *inorganic elements* of plants, comprehending the study of the soils from which these elements are derived, and

* The Durham County Agricultural Society, and the Members of the Durham Farmers' Club.

the general relations of geology to agriculture;—Part III., to the various methods, mechanical and chemical, by which the soil may be improved, and especially *to the nature of manures*, by which soils are made more productive, and the amount of vegetable produce increased;—and Part IV., to the *results of vegetation*, to the kind and value of the food produced under different circumstances, and its relation to the growth and feeding of cattle, and to the amount and quality of dairy produce.

By this method I have endeavoured to ascend from the easy to the apparently difficult; and I trust that the willing and attentive reader will find no difficulty in keeping by my side during the entire ascent.

The Author has much pleasure in now presenting these Lectures to the public in a complete form. He has only to express a hope that the delay which has occurred in the publication of the latter part of the work has enabled him to render it more useful, and therefore more worthy of the public approbation.

Durham, June, 1844.

NOTE.—The rapid sale of a large impression having rendered a second edition of the first and second Parts necessary before the entire completion of the work, such alterations, corrections, and additions only have been made as could be introduced without altering the original paging of the work. Several oversights, however, have been corrected, and some omissions supplied, which presented themselves in the earlier edition.

LECTURES

ON THE

APPLICATIONS OF CHEMISTRY AND GEOLOGY

TO

AGRICULTURE.

Part X.

ON THE ORGANIC ELEMENTS OF PLANTS.

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LECTURE I.

Importance of Agriculture—Relation of the growth of food to the population of Great Britain—Recent progress and prospects of English Agriculture—Application of Chemical and Geological Science to the art of culture—to the improvement of soils—the rotation of crops—the application of manures, &c.—Outline of the Course of Lectures—Number and nature of the elementary bodies—The organic elements Carbon, Hydrogen, Oxygen, and Nitrogen, their properties and their relations to vegetable life.

WERE I about to address you in a single or detached Lecture only, I should think it my duty to select some one branch of the art of culture for special illustration, and without much introductory matter to proceed at once to the exposition of the principle or principles on which it depended. As the present, however, is only the first of a Series of Lectures I hope to have the honor of delivering to you, I may be permitted to introduce my subject with a few prefatory remarks, which will here find their appropriate place.

In regard to the importance of Agriculture it may appear superfluous in me to address you. That art on which a thousand millions of men are dependent for their very sustenance—in the prosecution of which nine-tenths of the fixed capital of all civilized nations is embarked—and probably two hundred millions of men expend their daily toil—that art must confessedly be the most important of all; the parent and precursor of all other arts. In every country then, and at every period, the investigation of the principles on which the rational practice of this art is founded, ought to have commanded the principal attention of the greatest minds. To what other object could they have been more beneficially directed?

But there are periods in the history of every country when the study of Agriculture becomes more urgent, and in that country acquires a vastly superior importance. When a tract of land is thinly peopled, like the newly settled districts of North America, New Holland, or New Zealand, a very defective system of culture will produce food enough not only for the wants of the inhabitants, but for the partial supply of other countries also. But when the population becomes more dense, the same imperfect or sluggish system will no longer suffice. The land must be better tilled, its special qualities and defects must be studied, and means must gradually be adopted for extracting the maximum produce from every portion susceptible of cultivation.

The British islands are in this latter condition. Agriculture now is of vastly more importance to us as a nation, than it was towards the close even of the last century. In 1780, the island of Great Britain contained about 9 millions of inhabitants; it now contains nearly 20. The land has not increased in quantity, but the consumption of food has probably more than doubled. The importation from abroad has not increased to any important extent; by improved management, therefore, the same area of land has been caused to yield a double produce.

But the population will continue to increase; can we expect that the food raised from the land will continue to increase in the same ratio?

This is an important question, to which we can give only an imperfect and somewhat unsatisfactory answer.

The superficial area of Great Britain comprises about 57 millions of acres, of which 34 millions are in cultivation, about 13 millions are incapable of culture, and the remaining 10 millions are waste lands susceptible of improvement. The present population, therefore, is supported by the produce of 34 millions of acres, or every 34 acres raises food for about 20 people. Suppose the 10 millions of acres which are susceptible of improvement to be brought into such a state of culture as to maintain an equal proportion—the most favourable supposition—they would raise food for an additional population of about 6 millions, or would keep Great Britain independent of any large and constant foreign supply till the number of its inhabitants amounted to 26 millions. But at the present rate of increase this will take place in about 20 years,* so that by 1860, unless some general improvement take place in the agriculture of the country, the demands of the population will have completely overtaken the productive powers of the land.

But though we cannot say how far the fertility of the soil may be increased, or how long it may be able to keep a-head of the growing numbers of the people, we have our own past experience, the example of other countries, and the indications of theory, all concurring to persuade us that the limit of its productive powers can neither be predicted nor foreseen.

If we glance at the history of British agriculture during the last half century—from the introduction of the green crop system or the alternate husbandry from Flanders into Norfolk, up to the present time—we find the results of each successive improvement more remarkable than the former. The use of lime, a more general drainage of the soil, the invention of improved ploughs and other agricultural implements, as well as the introduction of better and more economical modes of using them, the application of bone manure, and more recently of thorough draining and subsoil ploughing, have all tended not only to the raising of crops at a less cost, but in far greater abundance, and on spots which our forefathers considered wholly unfit for the growth of corn.

The result of each new improvement, I have said, has seemed more astonishing than the former. For after a waste piece of land has been brought into an average state of productiveness, we are not prepared for any great improvement upon it by new labours; nor could we readily believe that, half a century after such land had been in culture, its produce or its value should at once be doubled, by a better draining, a deeper ploughing, or by sprinkling on its surface a small quantity of a saline substance imported from a foreign country.

Yet the example of the Chinese shows us that the productive powers of the soil are not to be easily estimated. Nothing repays the labours of the husbandman more fully than the willing soil—nothing is more grateful for his attention, or offers surer rewards to patient industry, or to renewed attempts at improvement.

In China we see a people whom we call semi-barbarians, multiplying within their own limits till their numbers are almost incredible;

* For more precise data and calculations see *Porter's Progress of the Nation.*

practising from the most remote ages, and in the most skilful manner, various arts which the progress of modern science has but recently introduced into civilized Europe; cultivating their soil with the most assiduous labour, and stimulating its fertility by means which we have hitherto neglected, despised, or been wholly ignorant of—but which the discoveries of the present time are pointing out as best fitted to secure the amplest harvests—and have thus been enabled to compel their limited soil to yield a sufficient sustenance to its almost unlimited population.*

Experience and example, therefore, encourage us to look forward to still further improvements in the art of culture, and, independent of such as may be derived from purely mechanical principles, theoretical chemistry seems to point out the direction in which important advances of another kind may reasonably be anticipated. The Chinese are said to be not only familiar with the relative value and efficiency of the various manures, but also to understand how to prepare and apply without loss that which is best fitted to stimulate and support each kind of plant. How far this statement is exaggerated we are unable at present to determine, but it is in this direction that chemistry appears likely to promote the advance of European agriculture. The practical farmer already rejoices in having in one ton of bone dust the equivalent of 14 tons of farm-yard manure; some of the most skilful living chemists predict that methods will hereafter be discovered for compressing into a still less bulky form the substances required by plants, and that we shall live to see extensive manufactories established for the preparation of these condensed manures.†

* An intelligent correspondent reminds me that the agricultural skill of the Chinese is questioned by recent writers on the customs of that country. This doubt is founded chiefly on the rudeness of their agricultural implements and the scarcity of cattle, whether horses or cows, among them. But in this densely peopled country the hoe they employ serves the purpose of every other implement (*Davis's China*, ii. 282), and where the place of cattle is supplied by an equivalent number of men, there can be no comparative want of valuable manure. The population of China, however, is probably not so dense in all the provinces as it has hitherto been supposed. Many writers have estimated the entire population at 300 millions, while recent statists reduce it to 175 millions. Taking even the higher estimate, the population is not more dense than in England and Holland—the area of China proper being 1,200,000 square miles, or eight times that of France. It is considerably less dense, indeed, if we take into account the number of horses and cattle which in Europe are reared and fed on the produce of the land. We may hereafter expect more accurate information, however, especially regarding the interior of this interesting country.—*See Appendix A.*

† Should the opinions above expressed appear too sanguine to some, or be treated by any of my readers as *merely theoretical*, I would refer them to the words of Mr. Smith of Deanston, the inventor of the subsoil plough, and the introducer of the greatest practical improvement in modern agriculture. After stating that *at least three-fourths of the whole arable land in the country is under very indifferent culture*, chiefly from the want of complete draining and deep working, and, adverting to the increased produce it may be made to yield, he says, "it is not at all improbable that Britain may become an exporting country in grain in the course of the next twenty years."—*Remarks on Thorough Draining and Deep Ploughing, by James Smith, Esq., of Deanston Works*, p. 22. Were the population to remain stationary, Mr. Smith may be right; at all events, this opinion shows that even practical men do not despair of attaining to a pitch of improvement in agriculture which theoretical writers dare not venture to predict.

But among all persons of enlarged information a similar opinion prevails. Thus the eloquent author of a recent work on the principles of population says, "the single alteration of substituting the kitchen-garden husbandry of Flanders in our plains, and the terraced culture of Tuscany in our hills, for the present system of agricultural management, would at once double the produce of the British islands, and procure ample subsistence for twice the number of its present inhabitants."—*Alison's Principles of Population*, I. p. 216. These hopes are not to be rejected or suppressed; for, though they may never be fully realized, yet they are, as it were, the seeds of exertion, from which ample harvests of good may hereafter be reaped.

Thus much may be said in regard to the future hopes and prospects of scientific agriculture.* But how few practical men are acquainted with what is already known of the principles of the important art by which they live! Trained up in ancient methods—attached generally to conservative principles in every shape—the practical agriculturists, as a body, have always been more opposed to change than any other large class of the community. They have been slow to believe in the superiority of any methods of culture which differed from their own, from those of their fathers, or of the district in which they live—and, even when the superiority could no longer be denied, they have been almost as slow to adopt them.

But the awakening spirit of the time is making itself felt in the remotest agricultural districts; old prejudices are dying out, and the cultivators of this most ancient, most important, and noblest of all the arts, are becoming generally anxious for information, and eager for improvement.†

Two circumstances have contributed to retard the approach of this better state of things.

In the first place, the agricultural interest in England has hitherto expended its main strength in attempting to secure or maintain important political advantages in the state. The encouragement of experimental agriculture has been in general neglected, while the diffusion of practical knowledge has been either wholly overlooked or considered subordinate to other objects. No national efforts have been made for the general improvement of the methods of culture. While for the other important classes of the community special schools have been established, in which the elements of all the branches of knowledge most necessary for each class have been more or less completely taught, and a more enlightened, because better instructed, race of men gradually trained up, no such schools have been instituted for the benefit of the agriculturist. In our Universities, in which the holders of land, those most interested in its improvement, are nearly all educated, a lesson upon agriculture, the right arm of the State, has hitherto scarcely ever been given.‡ With the practice of the art, the theory has also been

Those who have access to the Journal of the Royal English Agricultural Society will find in the first number a paper by Mr. Pusey, "On the present state of the science of Agriculture in England," in which much valuable information is contained, and of a more practical kind than I have been able to introduce. This paper ought to be printed in a separate form, and circulated widely among those who are not members of the Royal English Agricultural Society.

† This opinion has been confirmed by the numerous communications I have received from all parts of the country since the publication of these Lectures was announced, and in which I am assured that the want of knowledge is generally felt, and a supply in a sufficiently elementary form desired, by all classes of agriculturists. I conclude, therefore, that Liebig means the following sentence to apply to his German countrymen: "What can be expected from the present (generation of) farmers, which recoils with seeming distrust and aversion from all the means of assistance offered it by chemistry, and which does not understand the art of making a rational application of chemical discoveries." I do not think chemists ought in fairness to blame the practical agriculturists for not understanding the art of applying chemical discoveries to the improvement of the culture of the land. They must first know what the discoveries are; and the error has hitherto been, that no steps have been taken to diffuse this preliminary knowledge.

‡ However satisfied young men may be to avoid the labor of additional study while at College, how many in after-life regret that their early attention had not been directed to some of those branches of knowledge which are applicable to common life. Thus the late Lord Dudley, in his letters to the Bishop of Llandaff, invariably laments, "as mistakes in

neglected. Scientific men have had no inducement to devote their time and talents to a subject which held out no promise of reward, either in the shape of actual emolument or of honorary distinction. And thus has arisen the second of those circumstances, by which I consider the approach of a better state of things to have been retarded—namely, the want of an *Agricultural Literature.*

With the exception of a small number of periodical publications, none of these even too well supported, by which attempts have been zealously made to diffuse important information among the practical farmers—it cannot be denied that the press has not been encouraged to do its utmost on behalf of agricultural knowledge in general—while the single work of Sir Humphry Davy is nearly all that chemical science has, in this country, been induced to contribute to the advancement of agricultural theory during the last forty years.*

Many of you have probably read this work of Sir Humphry Davy, and are prepared to acknowledge its value. Yet how many things does he pass over entirely, how many things leave unexplained! Since his time, not only have numerous practical observations and discoveries been made, but the entire science of animal and vegetable chemistry has been regenerated. We are not, therefore, to expect in his work a view of the present state, either of our theoretical knowledge, or of our practical agriculture. It belongs rather to the history of the progress of knowledge, than to the condition of existing information. Hence the merits of the agricultural chemistry of Davy are not to be tried by its accordance with actual knowledge, but with what was known in 1812, when its distinguished author read his course of lectures for the last time before the Board of Agriculture.

We may with certainty predict, however, that neither the practice nor the theory of agriculture will be permitted to experience in future that want of general encouragement under which during the last half

his early life, his unacquaintance with the rudiments of agriculture—his ignorance of botany and geology."—(See also a note to the Review of these Letters in the Quarterly Review for December, 1840.)

For this state of things we shall soon have at least a partial remedy. It is a remarkable fact that nearly all the new educational institutions of the higher class, on the Continent of Europe, of which so many have been founded within the present century, and all those which have been established in America, I believe, without exception, have incorporated into their course of general study one or more of the newer sciences. Can we have a more consentaneous and universal testimony to their value and importance than this? The University of London has been induced, by the same public demand for this species of instruction, to include Chemistry and Botany in its course of arts; and circumstances only have caused Geology to be omitted for a time. Its numerous affiliated institutions have followed its steps; and hence the Catholic College of St. Cuthbert, at Ushaw, has in this respect anticipated its Protestant neighbor at Durham.

But should the agricultural interest rest satisfied with this introduction of one or two branches, suppose it generally done, into the University course of study? Many are of opinion that it ought not, and that the general interests of practical agriculture would be manifestly promoted, among other means, by the establishment of agricultural colleges, in which all the branches necessary to be known by enlightened agriculturists of every class should be specially and distinctly taught. Whether such Colleges might be beneficially annexed to the existing Universities, is a question deserving of serious consideration.

* The latest edition of Lord Dundonald's "Treatise on the intimate connection between Chemistry and Agriculture," which I have seen, is dated London, 1803.

I should be doing injustice to a good chemist and a zealous agriculturist, were I not to direct the attention of my readers to a series of excellent articles on chemical agriculture by Dr. Madden, inserted in the numbers of the Quarterly Journal of Agriculture for the last two years.

Since the above went to press, Three Lectures on Agriculture have appeared from the pen of Dr. Daubeny, of Oxford, whose name will secure them an extended circulation.

century they have in England been permitted to languish. The public mind has been awakened, and the establishment of Agricultural Associations, provincial and local, are manifestations of the interest now felt upon the subject in all parts of the country. It requires only the general exhibition of such an interest, and the adoption of some general means of encouragement, to stimulate both practical ingenuity and scientific zeal to expend themselves on this most valuable branch of national industry.

Science is never unwilling to lend her hand to the practical arts; on the contrary, she is ever forward to proffer her assistance, and it is not till her advances have been rejected or frequently repulsed, that she refrains from aiding in their advancement.

Need I advert, in proof of this, to the unwearied labours of the vegetable physiologists—or to the many valuable observations and experiments recorded in the memoirs of scientific chemists. In these memoirs, or in professedly scientific works, such observations have not unfrequently been permitted to rest;—the public mind being unprepared either to appreciate their value or to encourage the exertions of those who were willing to give them a practical and popular form.

And how numerous are the branches of science connected with this art? Need I speak of botany, which is, as it were, the foundation on which the first elements of agriculture rest; or of vegetable physiology, to the indications of which it has hitherto almost exclusively looked for improvement and increased success; or of zoology, which alone can throw light on the nature of the numerous insects that prey upon your crops, and so often ruin your hopes,—and which can alone be reasonably expected to arm you against their ravages, and instruct you to extirpate them? Meteorology among her other labours tabulates the highest, the mean, and the lowest, temperatures, as well as the quantity of rain which falls during each day and each month of the year. Do you doubt the importance of such knowledge to the proper cultivation of the land? Consider the destructive effects of a late frost in spring, or of a continued heat in summer, and your doubts will be shaken. A wet season in our climate brings with it many evils to the practical agriculturist; but what effect must the rain have on the soil, in countries where nearly as much falls in a month, as in England during the course of a whole year;*—where every thing soluble is speedily washed from the land, and nothing seems to be left but a mixture of sand and gravel? It may indeed be said with truth, that no department of natural science is incapable of yielding instruction—that scarcely any knowledge is superfluous—to the tiller of the soil.

It is thus that all branches of human knowledge are bound together, and all the arts of life, and all the cultivators of them, mutually dependent. And it is by lending each a helping hand to the others, that the success of all is to be secured and accelerated; while with the general progress of the whole the advance of each individual is made sure.

The recent contributions and suggestions of geology are the best proof of the readiness of the sciences of observation to give their aid to the promotion especially of agricultural knowledge. The geologist can best explain the immediate origin of your several soils, the cause of the

* At Canton, in the month of May, the fall of rain is often as much as 20 inches.

diversities which even in the same farm, it may be in the same field, they not unfrequently exhibit;* the nature and differences among your subsoils, and the advantages you may expect from breaking them up or bringing them to the surface.

Geology is essentially a popular science, and the talents of its eminent English cultivators are admirably fitted to make it still more so. Hence, a certain amount of knowledge of this science has been of late years very generally diffused, and its relations to agriculture are becoming every day better understood. The Highland Society of Scotland, among its many other useful exertions, has done very much to connect agriculture and geology with the sphere of its own labours, while the Journal of the Royal Agricultural Society of England manifests a similar desire on the part of that numerous and talented body, to illustrate the connection of agriculture with geology and chemistry, in the southern division of the island. That Dr. Buckland, Mr. Murchison, and Mr. De la Beche have each engaged to make a gratuitous survey of the subsoils in several extensive agricultural districts, at the request of the Council of this Society,† shows that, where their services are estimated, our most eminent scientific men will not hesitate to devote them to the development of the most important branches of national industry.

The time, therefore, is peculiarly favourable for the increase and diffusion of agricultural knowledge. The growth of our population requires it—practical men are anxious to receive instruction—scientific men are eager to impart what they know, and to make new researches for the purpose of clearing up what is unknown—are we not justified, therefore, in anticipating hereafter a constant and general diffusion of light, a steady progress of agricultural improvement?

Having thus glanced at the state and prospects of scientific agriculture in general, and especially of the art of culture in England, permit me to advert to a few of those questions of daily occurrence among you, to which chemistry alone can give a satisfactory answer. I shall not in this place allude to the subject of manures—which form alone an entire chapter of most recondite chemistry, and which I shall take up in its proper place, but I shall select a few isolated topics, the bearing of chemical knowledge upon which is sufficiently striking.

Some soils are naturally barren, but how few of our agriculturists are able, in regard to such soils generally, to say why; how few who possess the knowledge requisite for discovering the cause! Of these barren lands some may be improved so as amply to repay the outlay; some, from their locality or from other causes, are in the present state of our knowledge irreclaimable. How important to be able to distinguish between these two cases!

* I cannot refer to a plainer, more simple, or more beautiful illustration of this fact than that which is presented in a short paper by Sir John Johnstone, Bart., inserted in the Journal of the English Agricultural Society, I. p. 271, entitled "On the Application of Geology to Agriculture." See also an able paper by the Rev. Mr. Thorpe, of which a valuable report is contained in the Doncaster Chronicle of December 5th, and which will be published in the proceedings of the Geological and Polytechnic Society of the West Riding of Yorkshire.

† Journal of the Royal Agricultural Society, Report of their Council, I. p. 188.

To form a just idea of the value and importance of such surveys, it is only necessary to read chap. xv., pp. 463 to 480, of Mr. De la Beche's "Geological Report on Cornwall and Devon," or Professor Hitchcock's "Report on a re-examination of the Economic Geology of Massachusetts."

Some apparently good soils are yet barren in a high degree. In endeavouring to improve such soils, practical men have no general rule—they can have none. They work in the dark—like a man who makes experiments in a laboratory, without a teacher or without a book, till, after many blunders and much expense, he discovers some fact, to himself new, but to others long known, and forming only one of many analogous facts, flowing from a common, and probably well understood, principle.

"The application of chemical tests to such a soil," says Sir Humphry Davy, "is obvious. It must contain some noxious principle, [or be deficient in some necessary element.—J.] which may be easily discovered and probably easily destroyed. Are any of the salts of iron present, they may be decomposed by lime. Is there an excess of siliceous sand, the system of improvement must depend on the application of clay and calcareous matters. Is there a defect of calcareous matter, the remedy is obvious. Is an excess of vegetable matter indicated, it may be removed by liming, paring, and burning. Is there a deficiency of vegetable matter, it is to be supplied by manure."—[Agricultural Chemistry, Lecture I.]

What was true in regard to the applications of chemistry in the time of Sir Humphry Davy is more true in a high degree of the chemistry of our time. Not only is the nature of soils better understood, but we know in many cases what a soil *must* contain before it will produce a given crop. Why do pine forests settle themselves on the naked and apparently barren rocks of Scotland and of Northern Europe, content if their young roots can find but a crevice in the mountain to shelter them? Why does the beech luxuriate in the alluvial soils of Southern Sweden, of Zealand, and Continental Denmark? Why does the birch spring up from the ashes of the pine forest—why the rapid rush of delicate grass from the burned prairies of India and of Northern America? Whence comes the thick and tender sward of the mountain limestone districts—whence the gigantic wheat stalk of a virgin soil? Why do the same forest trees propagate themselves for ages on the same spots without impoverishing the soil—why do the natural grasses, the longer they are undisturbed, render the land only the more fertile?

These, one would think, are scarcely chemical questions, and yet to all of them, and to a thousand such, chemistry alone can and will give a satisfactory answer.

The rotation of crops is a practical rule, the benefit of which has been proved by experience; it becomes a true philosophical principle of action, when we discover the causes from which this benefit springs. Botany has thrown considerable light, and of an interesting and important kind, upon this practice, but chemistry has fully cleared it up and established the principle.

Sir Humphry Davy speaks of the use of lime. Can you explain the mysterious, and apparently fickle and diversified, agency of this substance in reference to vegetation? Are the advantages so frequently attendant upon its use to be ascribed to the chemical character of the soil to which it is applied, to the kind and quantity of the vegetable matter it contains, or to the geological nature of the rocks on which it rests? Are they dependent upon the drainage and exposure of the

land—on the kind of crop to be raised—on the general climate of the district—on the maxima and minima of temperature—or on the quantity of rain which falls?

So with gypsum. Why are its effects lauded in one district, doubted in another, and decried in a third! Are no rules or principles to be discovered, by which these diversified effects are to be explained, and the true purpose and fit use of these and other mineral substances clearly pointed out? Such principles are yet to be sought for; but if sought by the way of well devised and accurately conducted experiment, they are *sure* to be discovered.

The land is exhausted by frequent cropping. What language more familiar, what statement more true than this? Yet how few understand what exhaustion implies; how few can explain either how it takes place, by what means it can be remedied, or how, if left to herself, nature at length does apply a remedy!

Have you any doubt in regard to the prevailing ignorance on this subject? To be satisfied, you have only to look with an experienced eye on the agricultural practice of the county of Durham. Are there not thousands of acres in the centre of this county which exhibit a degree of unproductiveness not natural to the soil;—which have been overcropped, and worn out, and impoverished? A soil comparatively fertile by nature has been rendered unfertile by art. That which was naturally good has been rendered as unproductive and unprofitable as that which was naturally bad. Has this state of things arisen from ignorance, from design, or from necessity? By whichever of these it has been immediately caused, it is clear that the requisite degree of knowledge on the part of the owners of the soil would have retarded if not wholly prevented it.

The same knowledge will enable them to reclaim these lands again, and gradually restore them to a more fertile condition; for the changes which the soil undergoes in such circumstances are all chemical changes,—either in the relative quantities of the substances it contains, or in the state of combination in which they exist.

The art of culture indeed is almost entirely a chemical art, since nearly all its processes are to be explained only on chemical principles. If you add lime or gypsum to your land, you introduce new chemical agents. If you irrigate your meadows, you must demand a reason from the chemist for the abundant growth of grass which follows. Do you find animal manure powerful in its action, is the effect of some permanent, while that of others is speedily exhausted?—does a mixture of animal and vegetable manure prepare the land best for certain kinds of grain?—do you employ common salt, or gypsum, or saltpetre, or nitrate of soda, with advantage?—in all these cases you observe chemical results which you would be able to control and modify did you possess the requisite chemical knowledge.

It is not wonderful that even theoretical agriculturists should be far behind in the knowledge of those principles on which their most important operations depend. The greatest light has been thrown upon the art of culture by the researches of organic chemistry, a branch which may be said to have started, if not into existence, at least into a new life, within the last ten years. Every day too is adding to the number

and value of its discoveries, and the agriculturist may well be pardoned for not keeping pace with the advances of a department of science, which even the professed and devoted chemist can scarcely overtake.

I might advert also to the mechanical operations of ploughing, whether common or subsoil, of fallowing, draining, weeding, and many others, as being only so many methods by which chemical action is induced or facilitated;—to the growth of plants, and even to such observed differences as that of the relative quantity of leaves and tubers in the potatoe, and of grain and straw in our corn-fields, as interesting cases on which scientific chemistry throws a flood of light. I might shew how the feeding of your cattle and the raising and management of dairy produce are not beyond the province of chemistry, but that the only approach to scientific principle yet made, even in these branches of husbandry, is derived from the results of chemical research.

But I do not dwell on any of these points: they will all hereafter come under our review in their appropriate order, and will afford me an opportunity of laying before you many important facts, as well as, I hope, valuable practical deductions and observations.

While, however, I feel justified in saying thus much of the light which existing chemical knowledge throws on the natural processes of vegetation, and on the artificial methods of practical agriculture, I would not lead you to suppose that our knowledge is by any means complete, that there are not many points over which much darkness still rests—that some of the theoretical views now entertained are not crude, adopted too hastily, and generalized too rapidly. But a similar confession may be made in reference to all the modern sciences of observation without diminishing their importance or detracting from the value of the facts they embody. Human science is progressive in all its branches, and to refuse to follow the indications of existing knowledge because it is to some extent uncertain, would be as foolish as to refuse to avail ourselves of the morning's light, because it is not equal to that of the midday sun.

I advance, therefore, to the special object of these lectures, and I shall first present you with a rapid outline of the method which I intend to follow. It is indispensable that this method should be simple, and that every consecutive portion should be so fitted to clear the way for, and throw light upon, what is to follow, that we may be able to advance from the first rudiments to the most difficult and abstruse parts of our subject, without any chance of the illustrations being even difficult to comprehend. This end I do not hope perfectly to attain, but it will be my constant aim, and, with due attention on your part, I do not fear that we shall fail in arriving at a perfect understanding of the various points to which I shall have occasion to direct your attention.

I propose, therefore, to bring before you—

I. The constitution of vegetable substances with the properties of the elementary and compound bodies which either enter into the substances of plants or contribute to their growth and nourishment.

II. The general structure and functions of the several parts of plants

—their mode of growth—and the manner in which their food is absorbed, changed, and converted into parts of their substance.

III. The origin, nature, and principal differences of soils—with the circumstances on which their relative fertility depends, or under which it is modified.

IV. The nature and differences of manures, and their mode of action, whether directly in supplying food to the plant, or indirectly in hastening and increasing their growth.

V. The nature and diversities of the food raised as the result of culture—especially in reference to their several equivalents or powers of supporting animal life.

Under this head the feeding of cattle and the variations in the quantity and quality of dairy produce, will form subjects of consideration.

These different branches, I believe, comprehend the whole subject of chemical agriculture; in regard to all of them we shall derive either from chemistry or geology much important information.

§ 1. *Different kinds and states of matter.*

All the forms of matter which present themselves to our view, whether in the solid crust of the globe on which we live, in the air which forms the atmosphere by which we are surrounded, or in the bodies of animals and plants—all are capable of being divided into the two great groups of organic and inorganic matter. The solid rocks and soils, the atmosphere, the waters of the seas and oceans, every thing which neither is nor has been the seat of life, may generally be included under the head of inorganic matter. The bodies of all living animals and plants, and their dead carcases, consist of organic or organized matter. These generally exhibit a kind of structure readily visible by the eye, as in the pores of wood, and in the fibres of hemp, or of the lean of beef,* and are thus readily distinguished from inorganic matter, in which no such structure is observable.

But in many substances of organic origin also, no structure is observable. Thus, sugar, starch, and gum, are formed in plants in great abundance, and yet do not present any pores or fibres; they have never been endowed with organs, yet being produced by the *agency* of living organs, they are included under the general name of organic matter. So when animals and plants die, their bodies undergo decay, but the matter of which they are composed is considered as of organic origin, not only as long as any traces of structure are observable, but even after all such traces have disappeared. Thus coal is a substance of organic origin, though almost all traces of the vegetable matter from which it has been derived, have been long ago obliterated.

Again, heat chars and destroys wood, starch, and gum, forming black substances totally unlike the original matter acted upon. By distillation, wood yields tar and vinegar; and by fermentation, sugar is converted first into alcohol, and then into vinegar. All substances derived from vegetable or animal products by these and similar processes are included under the general designation of organic bodies.

* The pores of wood and fibres and minute vessels in animals being the *organs* or instruments of life, the substances themselves are called organized or organic.

Now if we take a portion of almost any of those numerous forms of matter which we meet with either in the inorganic or in the organic kingdoms, we find, that on subjecting it to certain chemical processes, it is capable of being resolved or separated into more than one substance. Thus coal when put into a gas retort is resolved into tar, coal gas, and certain other substances. Wood, when treated in the same way, yields pyroligneous acid, tar, and water, and leaves behind a residue of charcoal. If again we subject charcoal to the action of heat (not in the open air), or to any other process we can devise, we can never separate any thing further from it. After all our operations we obtain only charcoal.

So a piece of common lead ore, when heated in a similar manner, will, if pure, give off sulphur only, and leave the lead behind, from which nothing but lead can afterwards be extracted.

Thus it is evident that wood and the ore of lead differ from charcoal and metallic lead in this respect, that the former consist of more than one kind of matter, the latter of one kind of matter only. Hence charcoal and lead are called *simple* or *elementary* bodies, while wood and all other substances which are capable of being resolved into two or more different kinds of matter are called *compound* bodies.

The diversified forms of matter which present themselves to our notice in the mineral crust of the globe, and in the organs and vessels of plants and animals, are absolutely without number. We can no more reckon them than we can the stars of heaven. Yet it is one of those results of modern chemistry which to the mind not yet familiarized with chemical discoveries appears most wonderful,—that these numberless forms of matter are capable of being resolved into, and therefore are composed or made up of, only 55* of those simple or elementary substances, the nature of which has been above explained. Occasionally these elementary substances occur in a separate state, as in native [so called when found in the malleable state,] gold and silver, but they are generally found associated together, forming substances from which several of the 55 simple bodies may be extracted.

All the material substances in nature consist of one or more of these 55 elementary bodies. This is sufficiently surprising, yet it is, if possible, still more remarkable that nearly the entire mass of every vegetable substance may be resolved into one or more of *four* only of these simple substances.

When a portion of animal or vegetable matter is burned it either entirely disappears or leaves behind it only a small quantity of ash. Animal and vegetable oils and fats, gum, sugar, and starch, when burned, disappear entirely; a piece of wood or of lean meat leaves a small quantity of earthy (inorganic) matter behind.

Now all that disappears when any portion of vegetable matter, of any kind, is burned, consists generally of three, and only in some rare cases

* The names of these elementary bodies are as follows:—Oxygen, hydrogen, nitrogen, sulphur, selenium, phosphorus, chlorine, bromine, iodine, fluorine, carbon, boron, silicon, potassium, sodium, lithium, barium, strontium, calcium, magnesium, aluminium, glucinium, yttrium, zirconium, thorium, cerium, lanthanium, manganese, iron, cobalt, nickel, zinc, cadmium, lead, tin, bismuth, copper, uranium, mercury (quicksilver), silver, palladium, iridium, platinum, gold, osmium, titanium, tantalum (columbium), tungsten, molybdenum, vanadium, chromium, antimony, tellurium, arsenic.

of more than four, of the elementary bodies. These four are carbon, oxygen, hydrogen, and nitrogen. With the exception of the matter indestructible by fire (the ash), chemical analysis* has hitherto failed to detect the presence, in any notable quantity, of more than these four substances. The same remarks apply with almost equal truth to animal substances. The destructible part of these also consists of the same four elements.

To the agriculturist, therefore, an acquaintance with these four constituent parts of all that lives and grows on the face of the globe is indispensable. It is impossible for him to comprehend the laws by which the operations of nature in the vegetable kingdom are conducted, nor the reason of the processes he himself adopts in order to facilitate or to modify these operations, without this previous knowledge of the nature of the elements—the raw materials as it were—out of which all the products of vegetable growth are elaborated.

I shall first, therefore, exhibit to you briefly the properties of these *organic* constituents of plants, in order that we may be prepared for the further inquiries—by what means or in what form they enter into the circulation of plants—and how, when they have so entered, they are converted into those substances of which the skeleton of the plant consists or which are produced in its several organs.

§ 2. *Carbon—its properties and relations to vegetable life.*

Carbon is the name given by chemists to the substance of wood charcoal in its purest form. When wood is distilled in close vessels, or burned in heaps covered over, so as to prevent the free access of air, wood charcoal is left behind. When this process is well performed, the charcoal consists of carbon with a slight admixture only of earthy and saline matters, which remain behind on burning the charcoal in the air.

Heated in the air, charcoal burns with little flame, and, with the exception of the ash which is left, entirely disappears. It is converted into a kind of air known among chemists by the name of carbonic acid, which ascends as it is formed and mingles with the atmosphere.

Charcoal is light and porous, and floats upon water, but plumbago or black lead and the diamond, which are only other forms of carbon, are heavy and dense. The former is 2½, and the latter 3½, times heavier than water. The diamond is the purest form of carbon, and at a high temperature it burns in the air or in oxygen gas, and, like charcoal, disappears in the state of carbonic acid gas.

Of this carbon all vegetable substances contain a very large portion. It forms from 40 to 50 per cent., by weight, of all the parts of plants which are cultivated for the food of animals or of man, [that is, of these plants in their *dried* state.] In the economy of nature, therefore, it performs a most important part.

The light porous charcoals obtained from wood [especially from the willow, the pine, and the box], and from animal substances, possess several interesting properties, which are of practical application in the art of culture. 1°. They have the power of absorbing in large quantity into their pores, the gaseous substances and vapours which exist in

* Under the general name of chemical *analysis* are comprehended the various processes by which, as above explained, natural forms of matter may be resolved or separated into the several *elements* or simple substances of which they consist.

the atmosphere;* and on this property, as I shall explain hereafter, the use of charcoal powder as a manure probably in some measure depends. 2°. They also separate from water any decayed animal matters or colouring substances which it may hold in solution; hence its use in filters for purifying and sweetening impure river or spring waters, or for clarifying syrups and oils. This action is so powerful that port wine is rendered perfectly colourless by filtering through a well prepared charcoal.

In or upon the soil charcoal for a time will act in the same manner, will absorb from the air moisture and gaseous substances, and from the rain and from flowing waters organized matters of various kinds, any of which it will be in a condition to yield to the plants which grow around it, when they are such as are likely to contribute to their growth.

3°. They have the property also of absorbing disagreeable odours in a very remarkable manner. Hence animal food keeps longer sweet when placed in contact with charcoal—hence also vegetable substances containing much water, such as potatoes, are more completely preserved by the aid of a quantity of charcoal—and hence the refuse charcoal of the sugar refiners is found to deprive night-soil of its disagreeable odour, and to convert it into a dry and portable manure. 4°. They exhibit also the still more singular property of extracting from water a portion of the saline substances they may happen to hold in solution, and thus allowing it to escape in a less impure form. The decayed (half carbonized) roots of grass, which have been long subjected to irrigation, may act in one or all of these ways on the more or less impure water by which they are irrigated—and thus gradually arrest and collect the materials which are fitted to promote the growth of the coming crop.

§ 3. *Oxygen—its properties and relations to vegetable life.*

Oxygen is a substance with which we are acquainted only in the gaseous or aeriform state.† By the unaided senses it cannot be distinguished from common air, being void of colour, taste and smell. But if a lighted taper be plunged into it, the flame is wonderfully increased both in size and brilliancy, and the taper burns away with great rapidity.

The effect of this gas upon animal life is of a similar kind. When a living animal is introduced into a large vessel filled with oxygen, the rapidity of the circulation is increased, all the vital functions are stimulated and excited, a state of fever comes on, and after a time the animal dies.

By these two characters, oxygen is distinguished from every other elementary body. It exists in the atmosphere to the amount of 21 per cent. of its bulk, and in this state of air is necessary to the existence of animals and of plants, and to the support of combustion on the face of the globe. It exists also largely in water, every nine pounds of this liquid containing eight pounds of oxygen.

* Thus of ammonia they absorb 95 times their own bulk, of sulphuretted hydrogen 55 times, of oxygen 9 times, of hydrogen nearly twice their bulk, and of aqueous vapour so much as to increase their weight from 10 to 20 per cent.

† In this state it is readily obtained by heating in a glass retort the red oxide of mercury of the shops, or a white salt known by the name of chlorate of potash

But the quantity of this substance which is stored up in the solid rocks is still more remarkable. Nearly one-half of the weight of the solid rocks which compose the crust of our globe, of every solid substance we see around us—of the houses in which we live, and of the stones on which we tread—of the soils which you daily cultivate, and much more than one-half by weight of the bodies of all living animals and plants, consist of this elementary body oxygen, known to us, as I have already said, only in the state of a gas. It may not appear surprising that any one elementary substance should have been formed by the Creator in such abundance as to constitute nearly one-half by weight of the entire crust of our globe, but it must strike you as remarkable, that this should also be the element on the presence of which all animal life depends—and as nothing less than wonderful, that a substance which we know only in the state of thin air, should, by some wonderful mechanism, be bound up and imprisoned in such vast stores in the solid mountains of the globe, be destined to pervade and refresh all nature in the form of water, and to beautify and adorn the earth in the solid parts of animals and plants. But all nature is full of similar wonders, and every step you advance in the study of the principles of the art by which you live, you will not fail to mark the united skill and bounty of the same great Contriver.

Oxygen gas is heavier than common air in the proportion of about 11 to 10 [its specific gravity by experiment is 1·1026, air being 1]; it is also capable of being absorbed by water to a certain extent. One hundred measures of water dissolve 6¼ of this gas. [De Saussure. According to Dr. Henry, 100 volumes of water absorb only 3¼ of oxygen.] Rain, spring, and river waters, always contain a portion of oxygen which they have derived from the atmosphere, and this oxygen, as they trickle through the soil, ministers to the growth and nourishment of plants in various ways. Some of these will be explained in a subsequent lecture.

In an atmosphere of pure oxygen gas, plants refuse to vegetate, and speedily perish.

§ 4. *Hydrogen—its properties and relations to vegetable life.*

Hydrogen is also known to us only in the state of gas, and when perfectly pure agrees with oxygen and common air in being without colour, taste, or smell. It is not known to occur in nature in a free or simple state, nor does it exist so abundantly as either carbon or oxygen. It forms a small per centage of the weight of all animal and vegetable substances, and constitutes one-ninth of the weight of water, but with the exception of coal, it does not enter as a constituent into any of the large mineral masses that exist in the crust of the globe.

When a lighted taper is plunged into this gas it is immediately extinguished, but if in contact with the air the gas itself takes fire and burns with a pale yellow flame. If previously mixed with air or with oxygen gas, it kindles and burns with a loud explosion. During this combustion water is formed. [See the Second Lecture.]

It does not support life, animals cease to breathe when introduced into it, and plants gradually wither and die. It is the lightest of all known substances, being about 14½ times lighter than common air, so that if the stopper be removed from a bottle in which it is contained it almost imme-

diately escapes, [its specific gravity, by experiment, is 0·0687, air being 1.] It is the element which is employed to give buoyancy to balloons; and by this great levity and its relations to flame it is readily distinguished from all other known substances.

Water absorbs it only in very small quantities, 100 gallons taking up no more than about 1½ gallons of hydrogen gas. But, as already observed, this gas does not exist in nature in a free state—is not necessary, therefore, to the growth of plants or animals in this state—and hence its insolubility in water is in unison with the general adaptation of every property of every body, to the health and growth of the highest orders of living beings.

Hydrogen gas is readily obtained from water by putting into it a few pieces of metallic iron or zinc, and adding a little sulphuric acid (oil of vitriol). Bubbles of the gas are liberated from the surface of the metal, ascend through the water, and may be collected on the surface.

§ 5. *Nitrogen—its properties and relations to vegetable life.*

Nitrogen is also known to us only in the form of gas. It exists in the atmosphere to the amount of 79 per cent. of its bulk. It is without colour, taste, or smell. Animals and plants die in this gas, and a taper is instantly extinguished when introduced into it; the gas itself undergoing no change. It is lighter than atmospheric air, in the proportion of 97½ to 100, [its density is 0·976, air being 1.] It is an essential constituent of the air we breathe, serving to temper the ardour with which combustion would proceed and animals live in undiluted oxygen gas. It forms a part of very many animal and of some vegetable substances, but it is not known to enter into the composition of any of the great mineral masses of which the earth's crust is made up. In coal alone, which is of vegetable origin, it has been detected to the amount of one or two per cent. It is therefore much less abundant in nature than any of the other so called organic elements—and it exhibits much less decided properties than any of them; yet we shall hereafter see that it performs certain most important functions in reference both to the growth of plants and to the nourishment of animals.

One hundred volumes of water dissolve about 1½ volumes of this gas.* Spring and rain waters absorb it as they do oxygen, from the atmospheric air, and bear it in solution to the roots, by which it is not unlikely that it may be conveyed directly into the circulation of plants.

Such are the several elementary bodies of which the organic or destructible part of vegetable substances is formed. With one exception they are known to us only in the form of gases; and yet out of these gases much of the solid parts of animals and of plants are made up. When alone, at the ordinary temperature of the atmosphere they form invisible kinds of air; when united, they constitute those various forms of vegetable matter which it is the aim and end of the art of culture to raise with rapidity, with certainty, and in abundance. How difficult to understand the intricate processes by which nature works up these

* Henry De Saussure says, that pure water absorbs 4 per cent. of its bulk of this gas.

raw materials into her many beautiful productions—yet how interesting it must be to know her ways, how useful even partially to find them out!

Permit me, in conclusion, to submit to you one reflection. We have seen that oxygen, hydrogen, and nitrogen, are all gaseous substances, which when pure are destitute of colour, taste, and smell. They cannot be distinguished by the aid of our senses. Man in a state of nature —uneducated man—cannot discern that they are different. Yet so simple an instrument as a lighted taper at once shows them to be totally unlike each other. This simple instrument, therefore, serves us instead of a new sense, and makes us acquainted with properties the existence of which, without such aid, we should not even have suspected. Has the Deity then been unkind to man, or stinted in his benevolence in withholding the gift of such a sense? On the contrary, he has given us an understanding which when cultivated is better than twenty new senses. The chemist in his laboratory is better armed for the investigation of nature, than if his organs of sense had been many times multiplied. He has many instruments at his command, each of which, like the taper, tells him of properties which neither his senses nor any other of his instruments can discover; and the further his researches are carried, the more willing does nature seem to reveal her secrets to him, and the more rapidly do his chemical senses increase. Do you think that the rewards of study and patient experimental research are confined to the laboratory of the chemist, and that the Deity will prove less kind to you, whose daily toil is in the great laboratory of nature? As yet you see but faintly the reason of many of your commonest operations, and over the results you have comparatively little control—but the light is ready to spring up, the means are within your reach—you have only to employ your minds as diligently as you labour with your hands, and ultimate success is sure.

LECTURE II.

Characteristic properties of organic substances—Relative proportions of organic elements—Variable proportions of inorganic elements in plants—Form in which the organic elements are taken up by plants—The atmosphere, its constitution and relations to vegetable life—Nature and laws of chemical combination—Water and its relations to vegetable life

§ 1. *Characteristic properties of organic substances.*

Of the four elementary substances described in the former lecture, the organic part of all animal and vegetable substances consists. What is understood by the term organic has also been explained.

But organic substances possess certain characters by which they are distinguished from the inorganic or dead matter of the globe, and on which their connection with the principle of life, and with the art of culture, entirely depends. These characteristic properties are chiefly the following:

1°. They are all easily decomposed or destroyed by a moderately high temperature. If wood or straw be heated in the air, as over the flame of a candle, it becomes charred, burns, and is in a great measure dissipated. So sugar and starch darken in colour when heated, blacken, and take fire. The same is true of all vegetable substances. But limestone, clay, and other earthy or stony matters, undergo no apparent change in such circumstances—they are not decomposed.

2°. When exposed to the air, especially if it be warm and moist, vegetable and animal substances putrify and decay.* They decompose of their own accord, and after a time almost entirely disappear. Such is not the case with inorganic matters. If the rocks and stones crumble, their particles may be washed away by the rains to a lower level, but they never putrify or wholly disappear.

3°. They consist almost entirely of two or more of the four organic elements only. The mineral substances we meet with on the earth's surface, and collect for our cabinets, often contain portions of many elementary bodies; but, with few exceptions, the organic part of all plants, that which lives and grows, contains only the four simple substances described in my former lecture.

4°. They are distinguished also by this important character, that they cannot be formed by human art. Many of the inorganic compounds which occur in the mineral crust of the globe can be produced by the chemist in his laboratory, and were any corresponding benefit likely to be derived from the expenditure of time and labour, there is reason to believe that, with a few exceptions, nature might be imitated in the formation of any of her mineral productions. But in regard to organic substances, whether animal or vegetable, the chemist is perfectly at fault. He can form neither woody fibre, nor sugar, nor starch, nor muscular fibre, nor any of those substances which constitute the chief bulk of animals and plants, and which serve for the food of animated beings.

* For an explanation of the exact nature and end of this putrefaction, see the subsequen Lecture, "*On the decay of animal and vegetable substances.*"

This is an important and striking, and is, I believe, likely to remain a permanent distinction, between most substances of organic and of inorganic origin.

Looking back at the vast strides which organic chemistry has made within the last twenty years, and is still continuing to make, and trusting to the continued progress of human discovery, some sanguine chemists venture to anticipate the time when the art of man shall not only acquire a dominion over that principle of life, by the agency of which plants now grow and alone produce food for man and beast, but shall be able also, in many cases, to imitate or dispense with the operations of that principle: and to predict that the time will come when man shall manufacture by art those necessaries and luxuries for which he is now wholly dependent on the vegetable kingdom.

And, having conquered the winds and the waves by the agency of steam, is man really destined to gain a victory over the uncertain seasons too? Shall he come at last to tread the soil beneath his feet as a really useless thing—to disregard the genial shower, to despise the influence of the balmy dew—to be indifferent alike to rain and drought, to cloud and to sunshine—to laugh at the thousand cares of the husbandman—to pity the useless toil and the sleepless anxieties of the ancient tillers of the soil? Is the order of nature, through all past time, to be reversed—are the entire constitution of society, and the habits and pursuits of the whole human race, to be completely altered by the progress of scientific knowledge?

By placing before man so many incitements to the pursuit of knowledge, the will of the Deity is ,that out of this increase of wisdom he should extract the means of increased happiness and enjoyment also. But set man free from the necessity of tilling the earth by the sweat of his brow, and you take from him at the same time the calm and tranquil pleasures of a country life—the innocent enjoyments of the returning seasons—the cheerful health and happiness that wait upon labour in the free air and beneath the bright sun of heaven. And for what?—only to imprison him in manufactories, to condemn him to the fretful and feverish life of crowded cities.

To such ends, I trust, science is not destined to lead; and he is not only unreasonably, but thoughtlessly sanguine, who would hope to derive from organic chemistry such power over dead matter as to be able to fashion it into food for living animals. With such consequences before us it seems almost sinful to wish for it.

Yet, that this branch of science will lead to great ameliorations in the art of culture, there is every reason to believe. It will explain old methods—it will clear up anomalies, reconcile contradictory results by explaining the principles from which they flow—and will suggest new methods by which better, speedier, or more certain harvests may be reaped.

§ 2. *Relative proportions of organic elements.*

Though the substance of plants consists chiefly of the four organic elements, yet these bodies enter into the constitution of vegetables in very different proportions. This fact has already been adverted to in a general manner: it will appear more distinctly by the following statement of the exact quantities of each element contained in 1000 parts by

weight of some of the more important kinds of vegetable substance you are in the habit of cultivating :—

	Hay from young Clover 3 mos. old.	Oats.	Clover-Seed.	After-math Hay.	Peas.	Wheat.	Hay.	Potatoes.
Carbon . .	507	507	494	471	465	455	458	441
Hydrogen .	66	64	58	56	61	57	50	58
Oxygen . .	389	367	350	349	401	431	387	439
Nitrogen .	38	22	70	24	42	34	15	12
Ash . . .	not stated	40	28	100	31	23	90	50
	1000*	1000†	1000*	1000†	1000‡	1000*	1000†	1000†

The numbers in the above table represent the constitution of the plants and seeds, taken in the state in which they are given to cattle or are laid up for preservation, and then dried at 230° Fahrenheit. By this drying they lost severally as follows :

1000 parts of Potatoes . .	lost . . .	722	parts of water
ditto of Wheat . .	—	166	ditto
ditto of Hay . . .	—	158	ditto
ditto of Aftermath Hay	— .	136 to 140	ditto
ditto of Oats . . .	—	151	ditto
ditto of Clover Seed .	—	112	ditto
ditto of Peas . . .	—	86	ditto

In crops as they are reaped, therefore, and even as they are given for food, much water is present. When artificially dried, the carbon approaches to one-half of their weight—the oxygen to more than one-third§—the hydrogen to little more than 5 per cent.—and the nitrogen rarely to more than 2½ per cent. These proportions are variable, but they represent very nearly the relative weights in which these elements enter into the constitution of those forms of vegetable matter which are raised in the greatest quantity for the support of animal life.

But, besides the organic part, vegetable substances contain an inorganic portion, which remains behind in the form of ash when the plant is consumed by fire, or of dust when it decomposes and disappears in consequence of natural decay.

In the dried hay, oats, &c., of which the composition is represented in the above table, we see that the quantity of ash is very variable, in oats being as small as 4 per cent., while of hay every hundred pounds left 10 of ash. A similar difference is observed generally to prevail throughout the vegetable kingdom. Each variety of plant, when burned, leaves a weight of ash, more or less peculiar to itself. Herbaceous plants generally leave more than the wood of trees—and different parts of the same plant yield unlike quantities of inorganic matter.‖

* Boussingault Annales de Chim. et de Phys. (1838) LXVII. p. 20 to 38.

† Ditto ditto (1839) LXXI. p. 113 to 136.

‡ Ditto ditto (1838) LXIX. p. 356.

§ This will appear no way inconsistent with the statement in the former Lecture, that oxygen constitutes one-half by weight of all *living* plants, when it is recollected that of the water driven off in drying these plants eight-ninths by weight consist of oxygen, and that 600 lbs. of grass, for example, yield only from 80 to 100 lbs. of hay.

‖ Thus of the oak, the dried bark left 60 of ash—the dried leaves 53—the dried alburnum 4—and the dried wood only 2 parts in a thousand of ash.—*De Saussure.*

These facts are of great importance in the theory and in the enlightened practice of agriculture. They will hereafter come under special and detailed consideration, when we shall have examined the nature of the soils in which plants grow, and shall be prepared to consider the chemical nature, the source, and the functions, of the inorganic compounds which exist in living animal and vegetable substances.

§ 3. *Of the form or state of combination in which the organic elements enter into and minister to the growth of plants.*

From the details already presented in the preceding Lecture, in regard to the properties of carbon and nitrogen, and the circumstances under which they are met with in nature,—it will readily occur to you that neither of these elementary bodies is likely to enter directly, or in a simple state, into the circulation of plants. The former (carbon) being a solid substance, and insoluble in water, cannot obtain admission into the pores of the roots, the only parts of the plants with which, in nature, it can come in contact. The latter (hydrogen) does not occur either in the atmosphere or in the soil in any appreciable quantity, and hence, in its simple state, forms no part of the food of plants. Oxygen and nitrogen, again, both exist in the atmosphere in the gaseous state, and the former is known to be inhaled, under certain conditions, by the leaves of plants. Nitrogen may also in like manner be absorbed by the leaves of living plants, but, if so, it is in a quantity so small as to have hitherto escaped detection. The two latter substances (oxygen and nitrogen) are also slightly soluble in water, and, besides being inhaled by the leaves, may occasionally be absorbed in minute quantity along with the water taken in by the roots. But by far the largest proportion of these two elementary bodies, and the whole of the carbon and hydrogen which find their way into the interior of plants, have previously entered into a state of mutual combination—forming what are called distinct chemical compounds. Before describing the nature and constitution of these compounds, it will be proper to explain, 1°. the constitution of the atmosphere in which plants live, and, 2°. the nature of chemical combination and the laws by which it is regulated.

§ 4. *On the constitution of the atmosphere.*

The air we breathe, and in which plants live, is composed principally of a mixture of oxygen and nitrogen gases, in the proportion very nearly of 21 of the former to 79 of the latter. It contains, however, as a constituent necessary to the very existence of vegetable life, a small per centage of carbonic acid. On an average this carbonic acid amounts to about $\frac{1}{2500}$th part* of the bulk of the air. On the shores of the sea, or of great lakes, this quantity diminishes; and it becomes sensibly less as we recede from the land. It is also less by day than by night (as 3·38 to 4·32), and over a moist than over a dry soil.

The air is also imbued with moisture. Watery vapour is every where diffused through it, but the quantity varies with the season of the year, with the climate, with the nature of the locality, with its alti-

* 0·04 per cent. The mean of 104 experiments made by Saussure at Geneva at all times of the year and of the day gave 4·15 volumes in 10000. The maximum was 5·74, and the minimum 3·15.

tude, and with its distance from the equator. In temperate climates, it oscillates on the same spot between ½ and 1½ per cent. of the weight of the air; being least in mid-winter and greatest in the hot months of summer. There are also mingled with the atmosphere, traces of the vast variety of substances which are capable of rising from the surface of the earth in the form of vapour; such, for example, as are given off by decaying animal or vegetable matter—which are the produce of disease in either class of bodies—or which are evolved during the operations of nature in the inorganic kingdom, or by the artificial processes of man. Among these accidental vapours are to be included those miasmata, which, in certain parts of the world, render whole districts unhealthy,—as well as certain compounds of ammonia, which are inferred to exist in the atmosphere, because they can be detected in rain water, or in snow which has newly fallen.

In this constitution of the atmosphere we can discover many beautiful adaptations to the wants and structure of animals and plants. The exciting effect of pure oxygen on the animal economy is diluted by the large admixture with nitrogen;—the quantity of carbonic acid present is sufficient to supply food to the plant, while it is not so great as to prove injurious to the animal;—and the watery vapour suffices to maintain the requisite moisture and flexibility of the parts of both orders of beings, without in general being in such a proportion as to prove hurtful to either.

The air also, by its subtlety, diffuses itself everywhere. Into every pore of the soil it makes its way. When there, it yields its oxygen or its carbonic acid to the dead vegetable matter or to the living root. A shower of rain expels the half-corrupted air, to be succeeded by a purer portion as the water retires. The heat of the sun warms the soil, and expands the imprisoned gases,—these partially escape, and are, as before, replaced by other air when the rays of the sun are withdrawn.

By the action of these and other causes a constant circulation is, to a certain extent, kept up,—between the atmosphere on the surface, which plays among the leaves and stems of plants, and the air which mingles with the soil and ministers to the roots. The precise effect and the importance of this provision will demand our consideration in a future lecture.

§ 5. *The nature and laws of chemical combination.*

The terms *combine* and *combination* in chemical language have a strict and precise application. If sand and saw-dust be rubbed together in a mortar they may be intimately intermingled, but by pouring water on the mass we can separate the particles of wood and leave the sand unchanged behind. So if we stir oatmeal and water together, we may cause them perfectly to mix together, but by the aid of a gentle heat we can expel the water and obtain dry oatmeal in its original condition. Or, by putting salt into water, it will dissolve and disappear, and form what is called a solution, but by boiling it down, as is done in our salt-pans, the water may be entirely removed and the salt procured of the weight originally employed and possessed of its original properties.

In none of these cases has any chemical action taken place, or any

permanent change been produced, upon any of the substances. The two former were merely mixtures.

In all cases of chemical action a permanent change takes place in some of the substances employed; and this change is the result either of a chemical *combination*, or of a chemical *decomposition*.

Thus when sulphur is burned in the air, it is converted into white vapours possessed of a powerful and very unpleasant odour, and which continue to be given off until the whole of the sulphur is dissipated.

Here a solid substance is permanently changed into noxious vapours which disappear in the air, and this change is caused by the combination of the sulphur with the oxygen of the atmosphere.

In like manner when limestone is put into a kiln and strongly heated or burned, it is changed or converted into quicklime—a substance very different in its properties from the natural limestone employed. But this is a case of chemical *decomposition*. The limestone consists of lime and carbonic acid. By the heat these are separated, the latter is driven off and the former remains in the kiln.

Again, when a jet of hydrogen gas is kindled in the air or in oxygen gas, it burns with a pale yellow flame. If a cold vessel be held over this flame, it speedily becomes bedewed with moisture, and drops of water collect upon it. How remarkable the change which hydrogen undergoes during this combustion! It unites with the oxygen of the atmosphere and forms water. How different in its properties is this water from either the oxygen or the hydrogen by the union of which it is formed! The former a liquid, the latter gases; the former an enemy to all combustion, while of the latter, the one (hydrogen) burns readily, the other (oxygen) is the very life and support of combustion in all other bodies.

1°. It appears, therefore, that chemical combination or decomposition is always attended by a permanent change.

2°. That when combination takes place, a new substance is formed differing in its properties from any of those from which it was produced, or of which it consists.

When two or more elementary bodies thus unite together to form a new substance, this new substance is called a *chemical compound*. Thus water is a compound (not a mixture) of the two elementary bodies oxygen and hydrogen.

Now when such combination takes place, it is found to do so always in accordance with certain fixed laws. Thus:

I. Bodies unite together *only in constant and definite proportions*. We can *mix* together oxygen and hydrogen gases, for example, in any proportion, a gallon of the one with any number of gallons of the other, but if we burn two gallons of hydrogen gas in any greater number of gallons of oxygen, they will only consume or unite with one gallon of the oxygen, the rest of this gas remaining unchanged. A quantity of water will be formed by this union, in which the whole of the hydrogen will be contained, combined with all the oxygen that has disappeared. Under no circumstances can we burn hydrogen so as to cause it to consume more oxygen, or from a given weight of hydrogen to produce more than a known weight of water. And as oxygen is nearly sixteen times heavier than nitrogen, it is obvious that one gallon of the former is about

eight times heavier than two gallons of the latter, so that by weight these two gases, when thus burned, unite together nearly in the proportion of 1 to 8,—one pound of hydrogen forming nine pounds of water.

Again, when pure carbon is burned in the air, it unites with a fixed and constant weight of oxygen to form carbonic acid; it never unites with more, and it does not form carbonic acid when it unites with less.

Now this law of fixed and definite proportions is found to hold in regard to all bodies, and in all cases of chemical combination. Thus we have seen that—

	By weight.		By weight.	
	1 of hydrogen combines	with	8 of oxygen	to form water.
So	6 of carbon combine . . .		8	carbonic oxide,
and	14 of nitrogen		8	nitrous oxide.

Hence 1 of hydrogen, 6 of carbon, and 14 of nitrogen unite respectively with the weight (8) of oxygen. These several numbers, therefore, are said to be *equivalent* to each other (they are *equivalent numbers*). Or they represent the fixed and definite proportions in which these several substances combine together (they are *definite proportionals*). Some chemists consider these numbers to represent the relative weights of the atoms or smallest particles of which the several substances are made up, and hence not unfrequently speak of them as the *atomic weights* of these substances, or more shortly *their atoms*.

For the sake of brevity, it is often useful to represent the simple or elementary bodies shortly by the initial letter of their names. Thus hydrogen is represented by H, carbon by C, and nitrogen by N, and these letters are used to denote not only the substances themselves, but that quantity which is recognised as its *equivalent*, *proportional*, or *atomic weight*. Thus:

Symbol.		Equivalent or atomic weights.		Name.
H	denotes	1	by weight, of	hydrogen.
C	. . .	6	. . . . .	carbon.
O	. . .	8	. . . . .	oxygen.
N	. . .	14*	. . . . .	nitrogen.

Chemical *combination* is expressed shortly by placing these letters in juxta-position, or sometimes in brackets, with the sign plus (+) between them. Thus H O or (H + O) denotes the combination of one atom or equivalent of hydrogen with one of oxygen, that is, water; and at the same time a weight of water (9), equal to the sum of the atomic weights (1 + 8) of hydrogen and nitrogen.

A number prefixed or appended to a symbol, denotes that so many equivalents of the substance represented by the symbol are meant, as that number expresses. Thus 2 H O, 3 H O, or 3 (H + O), mean two or three equivalents of water, 3 H, or H_3 three equivalents of hydrogen, and 4 C or C_4, 2 N or N_2, four of carbon and two of nitrogen respectively.

II. Not only are the *quantities* of the substances which unite together definite and constant, but the *properties* or *qualities* of the substances formed are in general equally so. The properties of pure water or of

* More correctly 1, 6·13, 8·013, and 14·19.

carbonic acid are constant and invariable under whatever circumstances they may be formed, and the elements of which they consist, when they combine together in the same proportions, are never known to form any other compounds but water and carbonic acid.

This law, however, though generally, is not universally true. Many substances are known which contain the same elements united together in the same proportions, and which, nevertheless, possess very different properties. Oil of turpentine and oil of lemons are in this condition. They both consist of the same elements, carbon and hydrogen, united together in the same proportions, and yet their sensible properties as well as their chemical relations* are very dissimilar.

Cane sugar, starch, and gum, all of them abundant products of the vegetable kingdom, consist also of the same elements, carbon, hydrogen, and oxygen, united together in the same proportions, and may even be represented by the same *formula* ($C_{12} H_{10} O_{10}$),† and yet these substances are as unlike to each other in their properties, as many bodies are of which the chemical composition is very different. To compounds thus differing in their properties, and yet containing the same elements, in the same proportions, chemists have given the name of *Isomeric bodies*. I shall have occasion to make you more familiar with some of them hereafter.

3°. Another important law by which chemical combinations are regulated, is known by the name of the law of *multiple proportions*. Some substances are observed to be capable of uniting together in more than one proportion. Thus carbon unites with oxygen in several proportions, forming carbonic oxide, carbonic acid, oxalic acid, &c. Now when such is the case, it is found that the quantity (the weight) of each substance which enters into the several compounds, if not actually represented by the equivalent number or atomic weight, is represented by some simple multiple of that number. Thus two equivalents of carbon unite with 2, 3, or 4 equivalents of oxygen, to form carbonic oxide, oxalic acid, and carbonic acid respectively,—while one of nitrogen unites with 1, 2, 3, 4, or 5 of oxygen to form a series of compounds, of which the last ($N O_5$), nitric acid, is the only one I shall have frequent occasion to speak of in the present lectures.

This law of multiple proportions, though of great importance in chemical theory, I do not further illustrate, as we shall have very little occasion to refer to it in the discussion of the several topics which will hereafter come before us.

Having thus briefly explained the nature and laws of chemical combination, I proceed to make you acquainted with those chemical compounds of the organic elements which are known or are supposed to minister to the growth of plants.

The number of compounds which the four organic elements form with each other is almost endless; but of this number a very few only

* By the chemical relations of a substance are meant the effects which are produced upon it by contact with other chemical substances.

† This *formula* means that starch, gum, and sugar, consist of 12 equivalents of carbon united to 10 of hydrogen and 10 of oxygen.

are known to minister directly to the growth or nourishment of plants. Of these, water, carbonic acid, ammonia, and nitric acid, are the most important; but it will be necessary shortly to advert to a few others, of the occurrence or production or action of which we may hereafter have occasion to speak.

§ 6. *Of water and its relations to vegetable life.*

Water is a compound of oxygen and hydrogen in the proportion, as already stated, of 8 of the former to 1 of the latter by weight, or of 1 volume of oxygen to 2 of hydrogen.

It is more universally diffused throughout nature than any other chemical compound with which we are acquainted, performs most important functions in reference to animal and vegetable life, and is endowed with properties by which it is wonderfully adapted to the existing condition of things.

We are familiar with this substance in three several states of cohesion,—in the solid form as ice, in the fluid as water, and in the gaseous as steam. At 32° F. and at lower temperatures, it continues solid, at higher temperatures it melts and forms a liquid (water), which a 212° F. begins to boil and is converted into steam. By this change its bulk is increased 1700 times, and it becomes nearly two-fifths lighter than common air, [common air being 1, steam is 0·62.] It therefore readily rises into and diffuses itself through the atmosphere.

I. There are only one or two circumstances in which water in the solid form materially affects or interferes with the labours of the agriculturist.

1°. During the frost of a severe winter, the soil contracts and appears to shrink in. But the water contained in its pores freezes and expands, and the minute crystals of ice thus formed separate the particles of the soil from each other. This expansion of the water in dry soils may not be equal to the natural contraction of the soil itself, yet still it is sufficient to cause a considerable separation of the earthy particles throughout the whole frozen mass. When a milder temperature returns, and a thaw commences, the soil expands and gradually returns to its former bulk; but the outer layers thaw first, and the particles being previously separated by the crystals of ice, and now loosened by the thaw, fall off or crumble down, and thus the soil becomes exposed to the mellowing action of the atmosphere, which is enabled everywhere to pervade it. On heavy clay land this effect of the winter's frost not unfrequently proves very beneficial.*

2°. In the form of snow it has been often supposed to be beneficial to winter wheat and other crops. That a heavy fall of snow will shelter and protect the soil and crop from the destructive effects of any severe cold which may follow, there can be no doubt. It forms a light porous covering, by which the escape of heat from the soil is almost entirely prevented. It defends the young shoots also from those alternations of temperature to which the periodical return of the sun's rays continually

* This alternate contraction and expansion is often injurious to the practical farmer in *throwing out* his winter wheat. Some varieties are said to be more thrown out than others, and this peculiarity is sometimes ascribed to the longer and stronger roots which shoot from one variety than from another; it may, however, be occasionally owing to the different nature of the soils in which the trials have been made, or when, in the same soil, to the different states of dryness at different times.

exposes them;* and when a thaw arrives, by slowly melting, it allows the tender herbage gradually to accustom itself to the milder atmosphere.

In this manner there is no doubt that a fall of snow may often be of great service to the practical farmer. But some believe that winter wheat actually *thrives* under snow. On this point I cannot speak from personal knowledge, but I will here mention two facts concerning snow, which may possibly be connected with its supposed nourishing quality.

In the first place, snow generally contains a certain quantity of ammonia, or of animal matter which gives off ammonia during its decay. This quantity is variable, and is occasionally so small as to be very difficult of detection. Liebig found it in the snow of the neighbourhood of Giessen, and I have this winter detected traces of it in the snow which fell in Durham† during two separate storms. This ammonia is present in greater quantity in the first portions that fall and lie nearest the plant. Hence if the plant can grow beneath the snow, this ammonia may affect its growth; or when the first thaw comes it may descend to the root, and may there be imbibed. Rain water also contains ammonia, but when rain falls in large quantity it runs off the land, and may do less good than the snow, which lies and melts gradually. [For the properties of ammonia, see Lecture III.]

Another singular property of snow is the power it possesses of absorbing oxygen and nitrogen from the atmosphere, in proportions very different from those in which they exist in the air. The atmosphere, as already stated, contains 21 per cent. of oxygen by volume (or bulk), but the air which is present in the pores of snow has been found by various observers to contain a much smaller quantity. Boussingault [Annalen der Physick (Poggendorf), xxxiv., p. 211,] obtained from air disengaged by melting snow 17 per cent. of oxygen only, and De Saussure found still less. The difficulty of respiration experienced on very high mountains has been attributed to the nature of the air liberated from snow when melted by the sun's rays. Whether the air retained among the pores of the snow, which in severe winters covers our corn-fields, be equally deficient in oxygen with that examined by Boussingault, and whether, if it be, the abundance of nitrogen can at all affect vegetation, are matters that still remain undetermined.

II. In the fluid state, that of water, the agency of this compound in reference to vegetable life, though occasionally obscure, is yet everywhere discernible.

Pure water is a colourless transparent fluid, destitute of either taste or

* The effects of such alternations are seen on the occurrence of a night's frost in spring. If the sun's rays fall in the early morning, on a frozen shoot, it droops, withers, and blackens—it is destroyed by the frost. If the plant be in a shaded spot, where the sun does not reach it till after the whole atmosphere has been gradually heated, and the frozen tissue slowly thawed, its leaves sustain little injury, and the warmth of the sun's rays, instead of injuring, cherish and invigorate it. This effect of *sudden* alternations of temperature on organic matter explains many phenomena, to which it would here be out of place to advert.

A thick light covering of porous earth not beaten down preserves the potatoe pit from the effects of the frost better than a solid compact coating of clay, in the same way as snow protects the herbage better than a sheet of ice; and it is because of the porosity of the covering, that ice may be preserved more effectually, and for a longer period, in a similar pit, than in many well-constructed ice-houses.

† By adding two drops of sulphuric acid to four pints of snow water, evaporating to dryness, and mixing the dry mass with quicklime or caustic potash. The residual mass contained a brown organic matter, mixed with the sulphate of ammonia.

smell. It enters largely into the constitution of all living animals and plants, and forms upwards of one half of the weight of all the newly gathered vegetable substances we are in the habit of cultivating or collecting for the use of man. [See page 30.]

Not only does it enter thus largely into the constitution of all animals and plants, but in the existing economy of nature its presence in large quantities is absolutely necessary to the persistence of animal and vegetable life. In the midst of abundant springs and showers, plants shoot forth with an amazing rapidity, while they wither, droop, and die, when water is withheld. How much the manifestation of life is dependent upon its presence, is beautifully illustrated by some of the humbler tribes of plants. Certain mosses can be kept long in the herbarium, and yet will revive again when the dried specimens are immersed in water. At Manilla a species of Lycopodium grows upon the rocks, which, though kept for years in a dried state, revives and expands its foliage when placed in water [the Spaniards call it Triste de Corazon, Sorrow of the Heart.—*Burnet's Wanderings*, p. 72.] Thus life lingers as it were, unwilling to depart and rejoicing to display itself again, when the moisture returns.*

There are, however, three special properties of water, which are in a high degree interesting and important to the practical agriculturist, and to which I beg to direct your particular attention. These are:

1°. Its solvent power;

2°. Its affinity for certain solid substances; and,

3°. The degree of affinity by which its own elements are held together.

1°. When pure boiled water is exposed to the air, it gradually absorbs a quantity of the several gases of which the atmosphere is composed, and acquires more or less of a sparkling appearance and an agreeable taste. The air which it thus absorbs amounts to about $\frac{1}{30}$th of its own bulk, and is entirely expelled by boiling. When thus expelled, this air, like that obtained from snow, is found on examination to contain the oxygen, nitrogen, and carbonic acid in proportions very different from those in which they exist in the atmosphere. In the latter, oxygen is present to the amount of only 21 per cent. by volume, while the air absorbed by water contains 30 to 32 per cent. of the same gas. In like manner, the mean quantity of carbonic acid in the air does not exceed $\frac{5}{10000}$th parts (0·05 per cent.) of its bulk, while that expelled from water, which has been long exposed to the air, varies from 11 to 60 ten thousand parts (0·11 to 0·6† per cent.)

* In some species of animals, life is in like manner suspended by the absence of water. The inhabitants of some land and even marine shells may be dried and preserved for a long time in a state of torpor, and afterwards revived by immersion in water. The *Cerithium Armatum* has been brought from the Mauritius in a dry state, while snails are said to have been revived after being dried for 15 years. The *vibrio tritici* (a species of worm), was restored by Mr. Bauer, after an apparent death of nearly six years, by merely soaking it in water. The *Furcularia Anastobea*, a small microscopic animal, may be made to undergo apparent death and resuscitation many times, by alternate drying and moistening. According to Spallanzani, animalculi have been recovered by moisture, after a torpor of 27 years. These facts tend to lessen our surprise at the alleged longevity of the seeds of plants.

† Of these gases when unmixed, water absorbs very different quantities. Thus 100 volumes of water at 60° F., absorb 3·55 of oxygen, 1·53 of hydrogen, 1·47 of nitrogen, (*Henry*,) 106 of carbonic acid, or 7800 of ammonia.

Thus when water falls in rain or trickles along the surface of the land, it absorbs these gaseous substances, carries them with it wherever it goes, conveys them to the roots, and into the circulation of plants, and thus, as we shall hereafter see, makes them all minister to the growth and nourishment of living vegetables.

Again, water possesses the power of dissolving many solid substances. If sugar or salt be mixed with water in certain quantities, they speedily disappear. In like manner, many other bodies, both simple and compound, are taken up by this liquid in greater or less quantity, and can only be recovered by driving off the water, through the aid of heat.

Thus it happens that the water of our springs and rivers is never pure, but holds in solution more or less of certain solid substances. Even rain water, washing and purifying the atmosphere as it descends, brings down portions of solid matter which had previously risen into the air in the form of vapour, and as it afterwards flows along or sinks into the surface of the soil, it meets with and dissolves other solid substances, the greater portion of which it carries with it wherever it enters. In this way solid substances are conveyed to the roots of plants in a fluid form, which enables them to ascend with the sap; and the supply of these naturally solid substances is constantly renewed, by the successive passage of new portions of flowing water. We shall hereafter be able to see more clearly and to appreciate more justly this beautiful arrangement of nature, as well as to understand how indispensable it is to the continued fertility of the soil.

Nor is it merely earthy and saline substances which the water dissolves, as it thus percolates through the soil. It takes up also substances of organic origin, especially portions of decayed animal and vegetable matter,—such as are supposed to be capable of ministering to the growth of plants,—and brings them within reach of the roots.

This solvent power of water over solid substances is increased by an elevation of temperature. Warm water, for example, will dissolve Epsom salts or oxalic acid in much larger quantity than cold water will, and the same is true of nearly all solid substances which this fluid is capable of holding in solution. To this increased solvent power of the water they absorb, is ascribed, among other causes, the peculiar character of the vegetable productions, as well as their extraordinary luxuriance, in many tropical countries.

2°. But the *affinity* which water exhibits for many solid substances is little less important and remarkable.

When newly burned lime is thrown into a limited quantity of water the latter is absorbed, while the lime heats, cracks, swells, and finally falls to a white powder. When thus perfectly slaked, it is found to be one-third heavier than before—every three tons having absorbed one ton of water. This water is retained in a solid form, more solid than water is when in the state of ice, and it cannot be entirely separated from the lime without the application of a red heat. When you lay upon your land, therefore, four tons of slaked lime, you mix with your soil one ton of water, which the lime afterwards gradually gives up, either in whole or in part, as it combines with other substances. To this fact we shall return when we hereafter consider the various ways

in which lime acts, when it is employed by the farmer for the purpose of improving his land. [See the subsequent lecture, "*On the action of lime when employed as a manure.*"]

For clay also, water has a considerable affinity, though by no means equal to that which it displays for quicklime. Hence, even in well-drained clay lands, the hottest summer does not entirely rob the clay of its water. It cracks, contracts, and becomes hard, yet still retains water enough to keep its wheat crops green and flourishing, when the herbage on lighter soils is drooping or burned up.

A similar *affinity* for water is one source of the advantages which are known to follow from the admixture of a certain amount of vegetable matter with the soil; though, as in the case of charcoal, its porosity* is probably more influential in retaining moisture near the roots of the plants.†

3°. The degree of affinity by which the elements of water are held together, exercises a material influence on the growth and production of all vegetable substances.

If I burn a jet of hydrogen gas in the air, *water is formed* by the union of the hydrogen with the oxygen of the atmosphere, for which it manifests on many occasions an apparently powerful affinity. But if into a vessel of water I put a piece of iron or zinc and then add sulphuric acid, the *water is decomposed* and the hydrogen set free, while the metal combines with the oxygen.

So in the interior of plants and animals, water undergoes continual *de*composition and *re*composition. In its fluid state, it finds its way and exists in every vessel and in every tissue. And so slight, it would appear, in such situations, is the hold which its elements have upon each other—or so strong their tendency to combine with other substances, that they are ready to separate from each other at every impulse—yielding now oxygen to one, and now hydrogen to another, as the production of the several compounds which each organ is destined to elaborate respectively demands. Yet with the same readiness do they again re-attach themselves and cling together, when new metamorphoses require it. It is in the form of water, indeed, that nature introduces the greater portion of the oxygen and hydrogen which perform so important a part in the numerous and diversified changes which take place in the interior of plants and animals. Few things are really more wonderful in chemical physiology, than the vast variety of transmutations which are continually going on, through the agency of the elements of water.

III. In the state of vapour water ministers most materially to the life and growth of plants. It not only rises into the air at 212° Fahr. when it begins to boil, but it disappears or evaporates from open vessels at almost every temperature, with a rapidity proportioned to the previous dryness of the air, and to the velocity and temperature of the atmospheric currents which pass over it. Even ice and snow are grad-

* *Affinity* for water causes vegetable matter to combine chemically with it, *porosity* causes it merely to drink in the water mechanically, and to retain it, *unchanged*, in its pores.

† For an exposition of the intimate relation of water to the chemical constitution of the solid parts of living vegetables, see a subsequent Lecture, "*On the nature and production of the substances of which plants chiefly consist.*"

ually dissipated in the coldest weather, and sometimes with a degree of velocity which at first sight seems truly surprising.*

It thus happens that the atmosphere is constantly impregnated with watery vapour, which in this gaseous state accompanies the air wherever it penetrates, permeates the soil, pervades the leaves and pores of plants, and gains admission to the lungs and general vascular system of animals. We cannot appreciate the influence which, in this highly comminuted form, water exercises over the general economy of organic nature.

But it is chiefly when it assumes the form of rain and dew, and redescends to the earth, that the benefits arising from a previous conversion of the water into vapour become distinctly appreciable. The quantity of vapour which the air is capable of holding in suspension is dependent upon its temperature. At high temperatures, in warm climates, or in warm weather, it can sustain more—at low temperatures less. Hence when a current of comparatively warm air loaded with moisture ascends to or comes in contact with a cold mountain top, it is cooled down, is rendered incapable of holding the whole of the vapour in suspension, and therefore leaves behind in the form of a mist or cloud, a portion of its watery burden. In rills subsequently, or springs, the aqueous particles which float in the midst, re-appear on the plains beneath, bringing nourishment† at once, and a greateful relief to the thirsty soil.

So when two currents of air charged with moisture, but of unequal temperature, meet in the atmosphere, they mix, and the mixture has the mean temperature of the two currents. But air of this mean temperature is incapable of holding in suspeusion the mean quantity of watery vapour; hence, as before, a cloud is formed, and the excess of moisture falls to the earth in the form of rain. In descending to refresh the earth, this rain discharges in its progress another office. It washes the air as it passes through it, dissolving and carrying those accidental vapours which, though unwholesome to man, are yet fitted to minister to the growth of plants.

The dew, celebrated through all times and in every tongue for its sweet influence, presents the most beautiful and striking illustration of the agency of water in the economy of nature. and exhibits one of those wise and bountiful adaptations, by which the whole system of things, animate and inanimate, is fitted and bound together.

All bodies on the surface of the earth radiate, or throw out rays of heat, in straight lines—every warmer body to every colder; and the entire surface is itself continually sending rays upwards through the clear air into free space. Thus on the earth's surface all bodies strive, as it were, after an equal temperature (an equilibrium of heat), while

* Mr. Howard states that a circular patch of snow 5 inches in diameter lost in the month of January 150 grains of vapour between sunset and sunrise, and 56 grains more before the close of the day, when exposed to a smart breeze on a house-top. From an acre of snow this would be equal to 1000 gallons of water during the night only.—*Prout's Bridgewater Treatise, p. 302; Encyclopæd. Metropol., art. Meteorology.*

In Von Wrangell's account of his visit to Siberia and the Polar sea, translated by Major Sabine (p. 390), it is stated that, in the intense cold, not only living bodies—but the very *snow—smokes* and fills the air with vapour.

† For the nature of this *nourishment* see the subsequent Lectures, "*On the inorganic constituents of plants.*"

the surface as a whole tends gradually towards a cooler state. But while the sun shines this cooling will not take place, for the earth then receives in general more heat than it gives off, and if the clear sky be shut out by a canopy of clouds, these will arrest and again throw back a portion of the heat, and prevent it from being so speedily dissipated. At night, then, when the sun is absent, the earth will cool the most; on clear nights also more than when it is cloudy, and when clouds only partially obscure the sky, those parts will become coolest which look towards the clearest portions of the heavens.

Now when the surface cools, the air in contact with it must cool also; and like the warm currents on the mountain side, must forsake a portion of the watery vapour it has hitherto retained. This water, like the floating mist on the hills, descends in particles almost infinitely minute. These particles collect on every leaflet, and suspend themselves from every blade of grass, in drops of "pearly dew."

And mark here a beautiful adaptation. Different substances are endowed with the property of radiating their heat, and of thus becoming cool with different degrees of rapidity, and those substances which in the air become cool first, also attract first and most abundantly the particles of falling dew. Thus in the cool of a summer's evening the grass plot is wet, while the gravel walk is dry; and the thirsty pasture and every green leaf are drinking in the descending moisture, while the naked land and the barren highway are still unconscious of its fall.

How beautiful is the contrivance by which water is thus evaporated or distilled as it were into the atmosphere—largely perhaps from some particular spots,—then diffused equably through the wide and restless air,—and afterwards precipitated again in refreshing showers or in long-mysterious dews!* But how much more beautiful the contrivance, I might almost say the instinctive tendency, by which the dew selects the objects on which it delights to fall; descending first on every living plant, copiously ministering to the wants of each, and expending its superfluity only on the unproductive waste.

And equally kind and bountiful, yet provident, is nature in all her operations, and through all her works. Neither skill nor materials are ever wasted; and yet she ungrudgingly dispenses her favours, apparently without measure,—and has subjected dead matter to laws which compel it to minister, and yet with a most ready willingness, to the wants and comforts of every living thing.

And how unceasingly does she press this her example not only of unbounded goodness, but of universal charity—above all other men—on the attention of the tiller of the soil. Does the corn spring more freshly when scattered by a Protestant hand—are the harvests more abundant on a Catholic soil,—and does not the sun shine alike, and the dew descend, on the domains of each political party?

* The beauty of this arrangement appears more striking when we consider that the whole of the watery vapour in the air, if it fell at once in the form of rain, would not amount to more than 5 inches in depth on the whole surface of the globe. In England the fall of rain varies from 22 inches (London, York, and Edinburgh) to 68 (Keswick), while in some few parts of the world (St. Domingo) it amounts to as much as 150 inches. The mean fall of rain over the whole earth is estimated at 32 or 33 inches; but if we suppose it to be only 10 or 15 inches, the water which thus falls will require to be two or three times re-distilled in the course of every year. This is exclusive of dew, which in many countries amounts to a very large quantity.—See *Prout's Bridgewater Treatise*, p. 309.

So science, from her daily converse with nature, fails not sooner or later to take her hue and colour from the perception of this universal love and bounty. Party and sectarian differences dwindle away and disappear from the eyes of him who is daily occupied in the contemplation of the boundless munificence of the great Impartial; he sees himself standing in one common relation to all his fellow-men, and feels himself to be most completely performing his part in life, when he is able in any way or in any measure to contribute to the general welfare of all.

It is in this sense too that science, humbly tracing the footsteps of the Deity in all his works, and from them deducing his intelligence and his universal goodness—it is in this sense, that science is of no sect, and of no party, but is equally the province, and the property, and the friend of all.

§ 7. *Of the cold produced by the evaporation of water, and its influence on vegetation.*

Beautiful, however, and beneficent as are the provisions by which, in nature, watery vapour is made to serve so many useful purposes, there are circumstances in which, and often through the neglect of man, the presence of water becomes injurious to vegetation.

The ascent of water, in the form of vapour, permits the soil to dry, and fits it for the labours of the husbandman; while its descent in dew refreshes the plant, exhausted by the heat and excitement of a long summer's day. But the same tendency to ascend in vapour, gives rise to the cold unproductive character of lands in which water is present in great excess. This character you are familiar with in what are called *cold clay* soils.

The epithet *cold*, applied to such soils, though derived probably from no theoretical views, yet expresses very truly their actual condition. The surface of the fields in localities where such lands exist, is in reality less warm, throughout the year, than that of fields of a different quality, even in their immediate neighbourhood. This is readily proved, by placing the bulb of a thermometer immediately beneath the soil in two such fields, when in the hottest day a marked difference of temperature will, in general, be perceptible. The difference is dependent upon the following principle:—

When an open pan of water is placed upon the fire, it continues to acquire heat till it reaches the temperature of 212° F. It then begins to boil, but *ceases to become hotter*. Steam, however, passes off, and the water diminishes in quantity. But while the vessel remains upon the fire the water continues to receive heat from the burning fuel as it did before it began to boil. But since, as already stated, it becomes no hotter, the heat received from the fire must be carried off by the steam.

Now this is universally true. *Whenever water is converted into steam, the ascending vapour carries off much heat along with it.*

This heat is not missed, or its loss perceived, when the vapour or steam is formed over a fire; but let water evaporate in the open air from a stone, a leaf, or a field, and it must take heat with it from these objects—and the surface of the stone, the leaf, or the field, must become colder. That stone or leaf also must become coldest from which the largest quantity of vapour rises.

Now, let two adjoining fields be wet or moist in different degrees, that which is wettest will almost at all times give off the largest quantity of vapour, and will therefore be the coldest. Let spring arrive, and the genial sun will gently warm the earth on the surface of the one, while the water in the other will swallow up the heating rays, and cause them to re-ascend in the watery vapour. Let summer come, and while the soil of the one field rises at mid-day to perhaps 100° F. or upwards, that of the other may, in ordinary seasons, rarely reach 80° or 90°—in wet seasons may not even attain to this temperature, and only in long droughts will derive the full benefit of the solar rays. I shall hereafter more particularly advert to the important influence which a high temperature in the soil exercises over the growth of plants, the functions of their several parts, and their power of ripening seeds—as well as to certain beautiful adaptations by which nature, when left to herself, is continually imparting to the soil, especially in northern latitudes, those qualities which fit it for deriving the greatest possible benefit from the presence of the sun's rays. In the mean time you are willing to concede that warmth in the soil is favourable to the success of your agricultural pursuits. What, then, is the cause of the coldness and poverty, the fickleness and uncertainty of produce, in land of the kind now alluded to? It is the presence of too much water. What is the remedy? A removal of the excess of water. And how? By effectual drainage.

There are other benefits to the land, which follow from this removal of the excess of water by draining, of which it would here be out of place to treat; but a knowledge of the above principle shows you that the first effect upon the soil is the same as if you were to place it in a warmer climate, and under a milder sky—where it could bring to maturity other fruits, and yield more certain crops.

The application of this merely rudimentary knowledge will enable you to remove from many improvable spots the stigma of being *poor* and *cold*; an appellation hitherto applied to them,—not because they are by nature unproductive, but because ignorance, or indolence, or indifference, has hitherto prevented their natural capabilities from being either appreciated or made available.

Note.—In reference to the supposed fertilizing effect of snow, adverted to in the above lecture, I may mention a fact observed by Heyer, and quoted by Liebig, (p. 125), that willow branches immersed in snow water put forth roots three or four times longer than when put into pure distilled water, and that the latter remained clear while the snow water became coloured. This shows that snow contains something not present in distilled water, which is capable of accelerating the growth of plants. The experiment would have been more instructive in regard to natural operations, had the effect of the snow water been compared with that of an equal bulk of rain water, collected under similar circumstances.

LECTURE III.

Carbonic and oxalic acids, their properties and relations to vegetable life—Carbonic oxide and light carburetted hydrogen, their properties and production in nature—Ammonia, its properties and relations to vegetable life.

§ 1. *Carbonic acid, its properties and relations to vegetable life.*

When charcoal is burned in the air it combines slowly with oxygen, and is transformed into carbonic acid gas. In oxygen gas it burns more rapidly and vividly, producing the same compound.

This gas is colourless, like oxygen, hydrogen, and nitrogen, but is readily distinguished from all these, by its acid taste and smell, by its solubility in water, by its great density, and by its reddening vegetable blues. Water at 60 F. and under the ordinary pressure of the atmosphere, dissolves rather more than its own bulk of this gas (100 dissolve 106), and, however the pressure may be increased, it still dissolves the same bulk.

All gases diminish in bulk uniformly as the pressure to which they are subjected is increased. Thus under a pressure of two atmospheres they are reduced to one-half their bulk, of three atmospheres to one-third, and so on. When water, therefore, is saturated with carbonic acid under great pressure, as in the manufacture of soda water, though it still dissolves only its own bulk, yet it retains a weight of the gas which is proportioned to the pressure applied. For the same reason also, when the pressure is removed, as in drawing the cork from a bottle of water so impregnated, the gas expands and escapes, causing a lively effervescence, and the water retains only its own bulk at the existing pressure. This solution in water has a slightly sour taste, and reddens vegetable blues. These properties it owes to the presence of the gas, which is therefore what chemists call an *acid* body, and hence its name of carbonic *acid*. [Acids have generally a sour taste, redden vegetable blues, or combine with *bases*, such as lime, soda, potash, &c., to form *salts*.]

This gas is one-half heavier than atmospheric air, its density being 1·524, and hence it may be poured through the air from one vessel to another. Hence also, when it is evolved from crevices in the earth, in caves, in wells, or in the soil, this gas diffuses itself through the atmosphere and ascends into the air, much more slowly than the elementary gases described in the previous lecture. Where it issues from the earth in large quantity, as in many volcanic districts, it flows along the surface like water, enters into and fills up cracks and hollows, and sometimes reaches to a considerable distance from its source, before it is lost among the still air.

Burning bodies are extinguished in carbonic acid, and living beings, plunged into it, instantly cease to breathe. Mixed with one-ninth of its bulk of this gas the atmospheric air is rendered unfit for respiration. It is, however, the principal food of plants, being absorbed by their leaves and roots in large quantity. Hence the presence of carbonic acid in the atmosphere is necessary to the growth of plants, and they have been ob-

served to thrive better when the quantity of this gas in the air is considerably augmented. Common air, as has been already stated, does not contain more on an average than $\frac{1}{2500}$th of its bulk of carbonic acid, but De Saussure found that plants *in the sunshine* grew better when it was increased to $\frac{1}{13}$th of the bulk of the air, but beyond this quantity they were injured by its presence, even when exposed to the sun. When the carbonic acid amounted to one-half, the plants died in seven days; when it reached two-thirds of the bulk of the air, they ceased to grow altogether. In the shade any increase of carbonic acid beyond that which naturally exists in the atmosphere of our globe, was found to be injurious.

These circumstances it is of importance to remember. Did the sun *always shine* on every part of the earth's surface, the quantity of carbonic acid in the atmosphere might probably have been increased with advantage to vegetation. But every such increase would have rendered the air less fit for the respiration of existing races of animals. Thus we see that not only the nature of living beings, both plants and animals, but also the periodical absence of the sun's rays, have been taken into account in the present arrangement of things.

In perpetual sunshine plants would flourish more luxuriantly in air containing more carbonic acid, but they would droop and die in the shade. This is one of those proofs of *unity of design* which occasionally force themselves upon our attention in every department of nature, and compel us to recognise the regulating superintendence of *one mind*. The same hand which mingled the ingredients of the atmosphere, also set the sun to rule the day *only*,—tempering the amount of carbonic acid to the time of his periodical presence, as well as to the nature of animal and vegetable life.

Carbonic acid consists of one equivalent of carbon and two of oxygen, and is represented by CO_2. It unites with bases (potash, soda, lime, &c.), and forms compounds known by the name of *carbonate*. Thus *pearlash* is an impure *carbonates of potash*,—the common soda of the shops, *carbonate of soda*,—and limestone or chalk, *carbonates of lime*. From these compounds it may be readily disengaged by pouring upon them diluted muriatic or sulphuric acids. From limestone it is also readily expelled by heat, as in the common lime-kilns. During this process the limestone loses nearly 44 per cent. of its weight, [43·7 when pure and dry,] a loss which represents the quantity of carbonic acid driven off. [Hence by burning limestone on the spot where it is quarried, nearly one-half of the cost of transport is saved,]

Common carbonate of lime, in its various forms of chalk, hard limestone, or marble, is nearly insoluble in water, but it dissolves readily in water containing carbonic acid. Thus, if a current of this gas be passed through lime-water, the liquid speedily becomes milky from the formation and precipitation of carbonate of lime, but after a short time the cloudiness disappears, and the whole of the lime is re-dissolved. The application of heat to this clear solution expels the excess of carbonic acid, and causes the carbonate of lime again to fall.

By exposure to the air, we have already seen that water always absorbs a quantity of carbonic acid from the atmosphere. As it afterwards trickles through the rocks or through soil containing lime, it grad-

nally dissolves a portion of this earth, equivalent to the quantity of gas it holds in solution, and thus reaches the surface impregnated with calcareous matter. Or it carries it in its progress below the surface to the roots of plants, where its earthy contents are made available, either directly or indirectly, to the promotion of vegetable growth. To the lime thus held in solution, spring and other waters generally owe their *hardness*, and it is the expulsion of the carbonic acid, by heat, that causes the deposition of the sediment so often observed when such waters are boiled.

I propose hereafter to devote an entire lecture to the consideration of the action of lime upon land, as it is employed for agricultural purposes, but I may here remark, that this solvent action of the carbonic acid in rain water is one of the principal agents in removing the lime from your soils, and in rendering a fresh application necessary after a certain lapse of time. It is the cause also of that deposit of calcareous matter at the mouths of drains which you not unfrequently see in localities where lime is laid abundantly upon the land. The greater the quantity of rain, therefore, which falls in a district, the less permanent will be the effects of liming the land—the sooner will it be robbed of this important element of a fertile soil. Still carbonic acid is only one of several agents which act almost unceasingly in thus removing the lime from the land, a fact I shall hereafter have occasion more fully to explain.

In nature, carbonic acid is produced under a great variety of circumstances. It is given off from the lungs of all animals during respiration. It is formed during the progress of fermentation. Fermented liquors owe their sparkling qualities to the presence of this gas. During the decay of animal and vegetable substances in the air, in compost heaps, or in the soil, it is evolved in great abundance. In certain volcanic countries it issues in large quantity from springs and from cracks and fissures in the surface of the earth; while the vast amount of carbon contained in the wood and coal daily consumed by burning, is carried up into the atmosphere, chiefly in the form of carbonic acid. We shall hereafter consider the relation which exists between these several sources of supply and the proportion of carbonic acid permanently present in the air and so necessary to the support of vegetable life.

§ 2. *Oxalic acid, its properties and relations to vegetable life.*

Oxalic acid is another compound of carbon and oxygen, which, though not known to minister either to their growth or nourishment, is yet found largely in the interior of many varieties of plants. In an uncombined state it exists in the hairs of the chick pea. In combination with potash it is found in the wood sorrel (oxalis acetosella), in the common sorrel, and other varieties of *rumex*,—in which it is the cause of the acidity of the leaves and stems,—in the roots of these plants also, in the leaves and roots of rhubarb, and in the roots of tormentilla, bistort, gentian, saponaria, and many others. It is this combination with potash, formerly extracted from wood sorrel, which is known in commerce by the name of *salt of sorrel*. In combination with lime it forms the principal solid parts of

many lichens, especially of the *parmeliæ* and *variolariæ*,* some of which contain as much oxalate of lime as is equivalent to 15 or 20 parts of pure acid in 100 of the dried plant.

The crystallized oxalic acid of the shops forms transparent colourless crystals, of an intensely sour taste. These crystals dissolve readily in twice their weight of cold water, and the solution, when sufficiently dilute, is agreeably acid to the taste. This acid is exceedingly poisonous. Half an ounce of the crystals is sufficient to destroy life in a very short time, and a quarter of an ounce after the lapse of a few days. It consists solely of carbon and oxygen in the proportion of two equivalents of the former to three of the latter. Its symbol is C_2O_3. It combines with bases, and forms salts which are known by the name of *oxalates*, and it is characterised by the readiness with which it combines with lime to form *oxalate of lime*. If a solution of the acid be poured into lime water, the mixture immediately becomes milky from the formation of this compound, which is insoluble in water.† It is this *oxalate of lime* which exists in the lichens, while *oxalate of potash* exists in the sorrels.

Oxalic acid is one of those compounds of organic origin which we cannot form, as we can form carbonic acid by the direct union of its elements. In all our processes for preparing it artificially, we are obliged to have recourse to a substance previously *organized* in the living plant. It may be prepared from sugar, starch, or even from wood, by various chemical processes. The usual method is to digest potato starch with five times its weight of strong nitric acid (aquafortis), diluted with ten of water, till red fumes cease to be given off, and then to evaporate the solution. The oxalic acid separates in crystals, or, as it is usually expressed, *crystallizes* in the solution thus concentrated by evaporation.

It is not known to exist in the soil or in the waters which reach the roots of plants. Where it is found in living vegetables, therefore, it must, like the other substances they contain, have been formed or elaborated in the interior of the plant itself. By what very simple changes the production of this acid is or may be effected, we shall see in a subsequent lecture.

§ 3. *Carbonic oxide, its constitution and properties.*

When carbonic acid (CO_2) is made to pass through a tube containing red-hot charcoal, it undergoes a remarkable change. Its gaseous form remains unaltered, but it combines with a second equivalent of carbon (becoming C_2O_2), which it carries off in the aeriform state. The new

* The *parmelia cruciata* and *variolaria communis* are mentioned as peculiarly rich in this acid, which used to be extracted from them for sale. A species of parmelia, collected after the droughts on the sands of Persia and Georgia, contains 66 per cent. of oxalate of lime, with about 22 per cent. of a gelatinous substance similar to that obtained from Iceland moss. This lichen is used for food by the Kirghuis. A similar lichen is collected about Bagdad for a similar purpose.

† Substances that are insoluble are generally without action on the animal economy, and may be introduced into the stomach without producing any injurious effect. Hence this oxalate of lime, though it contains oxalic acid, is not poisonous. Hence also, if oxalic acid be present in the stomach, its poisonous action may be taken away by causing lime water or milk of lime to be swallowed in sufficient quantity. The acid combines with the lime, as in the experiment described in the text, and forms insoluble oxalate of lime. The common magnesia of the shops will serve the same purpose, forming an insoluble *oxalate of magnesia*. It is by performing experiments under circumstances where the results are visible—as in glass vessels—that we are enabled to predict the results in circumstances where the phenomena are not visible, and to act with as much confidence as if we could really see them.

gas thus produced is known by the name of carbonic oxide. It consists of one equivalent of carbon united to one of oxygen, and is represented by C_2O_2, or simply CO.

This gas is colourless, without taste or smell, lighter than common air, nearly insoluble in water, extinguishes flame, does not support life; burns in the air or in oxygen gas with a blue flame, and during this combustion is converted into carbonic acid. It is produced along with carbonic acid during the imperfect combustion of coals in our fires and furnaces, but is not known to occur in nature, or to minister directly to the growth of plants.

There exists a general relation among the three compounds of carbon and oxygen above described, to which it may be interesting to advert, in connection with the subject of vegetable physiology. This relation appears when we compare together their chemical constitution, as represented by their chemical formulæ :—

Carbonic acid consists of one of carbon and two of oxygen, or CO_2;

Carbonic oxide, of one of carbon and one of oxygen, or CO;

So that if carbonic acid be present in a plant, and be there deprived of one equivalent of its oxygen, by any vital action, it will be converted into carbonic oxide.

Oxalic acid consists of two of carbon and three of oxygen, or C_2O_3.

If we add together the formulæ for

$$\begin{aligned} \text{Carbonic acid} &= CO_2 \text{ and} \\ \text{Carbonic oxide} &= CO, \text{ we have} \\ \hline \text{Oxalic acid} &= C_2O_3. \end{aligned}$$

Hence this acid may be formed in the interior of plants, either by the direct union of carbonic oxide and carbonic acid, or by depriving two of carbonic acid ($2CO_2$ or C_2O_4) of one equivalent of oxygen.

When in a subsequent lecture we have studied the structure and functions of the leaves of plants, we shall see how very easy it is to understand the process by which oxalic acid is formed and deposited in the interior of plants, and by which carbonic oxide also *may be*, and probably is, produced.

§ 4. *Light carburetted hydrogen—the gas of marshes and of coal mines.*

During the decay of vegetable matter in moist places, or under water, a light inflammable gas is not unfrequently given off, which differs in its properties from any of those hitherto described. In summer it may often be seen rising up in bubbles from the bottom of stagnant pools and from marshy places, and may readily be collected.

This gas is colourless, without taste or smell, and is little more than half the weight of common air, [its specific gravity, by experiment, is 0·5576.] A lighted taper, plunged into it, is immediately extinguished, while the gas takes fire and burns with a pale yellow flame, yielding more light, however, than pure hydrogen gas, which it otherwise resembles. Animals introduced into it, instantly cease to breathe.

It consists of one equivalent of carbon (C) united to two of hydrogen (2H or H_2), and is represented by CH_2. When burned in the air or

in oxygen gas, the carbon it contains is converted into carbonic acid (CO_2), and the hydrogen into water (HO).

Like oxalic acid this gas cannot, by any known process, be produced from the direct union of the carbon and hydrogen of which it consists. It is readily obtained, however, by heating acetate of potash in a retort, with an equivalent proportion of caustic baryta. [*Acetate* of potash is prepared by pouring vinegar (acetic acid) on common pearlash and evaporating the solution.]

In nature it is largely evolved in coal mines, and is the principal combustible ingredient in those explosive atmospheres which so frequently cause disastrous accidents in mining districts.

This gas is also given off along with carbonic acid during the fermentation of compost heaps, or of other large collections of vegetable matter. It is said also to be generally present in well manured soils, [PERSOZ, *Chimie Moleculaire*, p. 547,] and is supposed by many to contribute in such cases to the nourishment of plants. It is, however, very sparingly soluble in water, so that in a state of solution, it cannot enter largely into the pores of the roots, even though it be abundantly present in the soil. How far it can with propriety be regarded as a general source of food to plants, will be considered in the following lecture.

§ 5. *Ammonia, its properties and relations to vegetable life.*

Ammonia is a compound of hydrogen and nitrogen. It is possessed of many interesting properties, and is supposed to perform a very important part in the process of vegetation. It will be proper, therefore, to illustrate its nature and properties with considerable attention.

Ammonia, like the nitrogen and hydrogen of which it is composed, is a colourless gas, but, unlike its elements, is easily distinguished from all other gaseous substances by its smell and taste.

It possesses a powerful penetrating odour (familiar to you in the smell of hartshorn and of common smelling salts), has a burning acrid alkaline* taste, extinguishes a lighted taper as hydrogen and nitrogen do, but does not itself take fire like the former. It instantly suffocates animals, kills living vegetables, and gradually destroys the texture of their parts.

It is absorbed in large quantities by porous substances, such as charcoal—which, as already stated, absorbs 95 times its own bulk of ammoniacal gas. Porous vegetable substances in a decaying state likewise absorb it. Porous soils also, burned bricks, burned clay, and even common clay and iron ochre, which are mixed together on the surface of most of our fertile lands—all these are capable of absorbing or drinking in, and retaining within their pores, this gaseous substance, when it happens to be brought into contact with them.

But the quantity absorbed by water is much greater and more surprising. If the mouth of a bottle filled with this gas be immersed in water, the latter will rush up and fill the bottle almost instantaneously; and if a sufficient supply of ammonia be present, a given quantity of water will take up as much as 670 times its bulk of the gas.

This solution of ammonia in water is the spirit of hartshorn of the shops. When *saturated* [that is, when gas is supplied till the water re-

* The term *alkaline*, as applied to taste, will be best understood by describing it as a taste similar to that of the common soda and pearlash of the shops.

fuses to take up any more,] it is lighter than pure water, [its specific gravity is 0·875, water being 1,] has the pungent penetrating odour of the gas, and its hot, burning, alkaline taste—is capable of blistering the skin, and decomposing or destroying the texture of animal and vegetable substances.

You will remark here the effect which combination has in investing substances with new characters. The two gases hydrogen and nitrogen, themselves without taste or smell, and absorbed by water in minute quantity only, form by their union a compound body remarkable both for taste and smell, and for the rapidity with which water absorbs it.

Ammonia possesses also alkaline properties,* it restores the blue colour of vegetable substances that have been reddened by an acid, and it combines with acid substances to form salts.

Among gaseous substances, therefore, there are some which, like carbonic acid, have a sour taste and redden vegetable blues; others which, like ammonia, have an alkaline taste and restore the blue colour; and a third class which, like oxygen, hydrogen, and nitrogen, are destitute of taste and do not affect vegetable colours. These last are called *neutral* or indifferent substances.

Ammonia, as above stated, combines with acids and forms salts, which at the ordinary temperature of the atmosphere are all solid substances. Hence if carbonic acid gas be mixed with ammoniacal gas, a white cloud is formed consisting of minute particles of solid *carbonate* of *ammonia*—the smelling salts of the shops. Hence also a feather dipped into vinegar or dilute muriatic acid (spirit of salt), and then introduced into ammoniacal gas, forms a similar white cloud, and becomes covered with a white down of solid *acetate* or of *muriate* of ammonia (sal ammoniac). The same appearance is readily seen by holding the feather to the mouth of a bottle containing hartshorn (liquid ammonia), from which ammoniacal gas continually escapes, and by its lightness rises into the air, and thus comes in contact with the acid upon the feathers.

The fact of the production of a solid body by the union of two gases (ammonia and carbonic or muriatic acid gases) is one of a very interesting nature to the young chemist, and presents a further illustration of the *changes* resulting from chemical combination as explained in the previous lecture.

Ammonia is little more than half the weight of common air, [more nearly three-fifths, its specific gravity being 0·59, that of air being 1,] hence when liberated on the earth's surface it readily rises into and mingles with the atmosphere. It consists of hydrogen and nitrogen united together in the proportion of three equivalents of hydrogen (3H or H_3) and one of nitrogen (N), [see Lecture II,] and hence it is represented by the symbol (N + 3H), or more shortly by NH_3. 100 parts by weight contain 82½ of nitrogen and 17½ of hydrogen, [correctly 82·545 and 17·455 respectively.]

In nature, ammonia exists in considerable quantity. It is widely,

* In the previous lecture, the term *acid* was explained as applying to substances possessed of a sour taste, and capable of reddening vegetable blues or combining with *bases* (potash, soda, magnesia, &c.) to form *salts*; *alkalies* are such as possess an alkaline taste (see previous Note), restore the blue colour to reddened vegetable substances, or combine with *acids* to form *salts*. Of salts, nitrate of soda, saltpetre (nitrate of potash), and glauber salts (sulphate of soda), are examples.

almost universally, diffused, but is not known to form large deposits on any part of the earth's surface, or to enter as a constituent into any of the great mineral masses of which the crust of the globe is composed. It exists most abundantly in a *state of combination*—in the forms, for example, of muriate (sal ammoniac), of nitrate, and of carbonate of ammonia. It frequently escapes into the atmosphere in an uncombined state, especially where animal matters are undergoing decay, but it rarely exists in this free state for any length of time. It speedily unites with the carbonic acid of the air, with one or other of the numerous acid vapours which are continually rising from the earth, or with the nitric acid which is formed at the expense of the nitrogen and oxygen of which the atmosphere consists.

The influence of ammonia on vegetation appears to be of a very powerful kind. It seems not only to promote the rapidity and luxuriance of vegetation, but to exercise a powerful control over the functions of vegetable life. In reference to the nature and extent of this action, into which we shall hereafter have occasion to inquire, there are several special properties of ammonia which it will be of importance for us previously to understand.

1°. It has a powerful affinity* for acid substances. Hence the readiness with which it unites with acid vapours when it rises into the atmosphere. Hence also when formed or liberated in the soil, in the fold-yard, in the stable, or in compost heaps, it unites with such acid substances as may be present in the soil, &c. and forms saline compounds or *salts*. All these salts appear to be more or less influential in the processes of vegetable life.

2°. Yet this affinity is much less strong than that which is exhibited for the same acids by potash, soda, lime, or magnesia. Hence if any of these substances be mixed or brought into contact with a salt of ammonia, the acid of the latter is taken up by the potash or lime, while the ammonia is separated in a gaseous state. Thus when sal ammoniac in powder is mixed with twice its weight of quick-lime, ammoniacal gas is liberated in large quantity. This is the method by which pure ammonia is generally prepared; and one of the *many* functions performed by lime when employed for the improvement of land, especially on soils rich in animal and vegetable matter, is that of decomposing the salts, especially the organic salts, of ammonia,—as will be more fully explained when we come to treat at length of this important part of agricultural practice.†

3°. The salts which ammonia forms with the acids are all, like ammonia itself, very soluble in water. Hence two consequences follow. First, that which rises into the air in the form of gas, and there combines with the carbonic or other acids, is readily dissolved, washed out

* By *affinity* is meant the tendency which bodies have to unite and to remain united or combined. Thus ammonia forms a solid substance with the vapour of vinegar the moment the two substances come into contact; they have, therefore, a strong tendency to unite, or an *affinity* for each other.

† See Lecture XVI. "*On the use of lime.*" Owing to this property the action of lime upon compost heaps is often injurious, by causing the evolution of the ammonia produced during the decomposition of the animal matters they contain. This escape of ammonia, even when imperceptible by the sense of smell, is easily detected by holding over the heap a feather dipped in vinegar or in spirit of salt (muriatic acid), when white fumes are immediately perceived if ammonia be present.

and brought to the earth again by the rains and dews; so that at the same time the air is purified for the use of animals, and the ammonia brought down for the use of plants. And second, whatever salts of ammonia are contained in the soil, being dissolved by the rain, are in a condition to be taken up, when wholesome, by the roots of plants; or to be carried off by the drains when injurious to vegetation.

4°. I have already alluded to the fact of this gas being absorbed by porous substances, and to its presence, in consequence, in porous soils, and in burned bricks and clay. With the purer kinds of unburned clay, however, and with the oxide of iron contained in red (or ferruginous)* soils, ammonia is supposed to form a chemical compound of a weak nature. In consequence of its affinity or feeble tendency to combine with these substances, they attract it from the air, and from decaying animal or vegetable matters, and retain it more strongly than many porous substances can,—yet with a sufficiently feeble hold to yield it up, readily as is supposed, to the roots of plants, when their extremities are pushed forth in search of food. In this case the carbonic, acetic, and other acids given off, or supposed to be given off by the roots, exercise an influence to which more particular allusion will be made hereafter.

6°. In the state of carbonate it decomposes gypsum, forming carbonate of lime (chalk) and sulphate of ammonia.† The action of gypsum on grass lands, so undoubtedly beneficial in many parts of the world, has been ascribed to this *single* property; it being supposed that the sulphate of ammonia formed, is peculiarly favourable to vegetation. This question will come properly under review hereafter. I may here, however, remark that if this be the *sole* reason for the efficiency of gypsum, its application ought to be beneficial on all lands not already abounding either in gypsum or in sulphate of ammonia.‡ But if the

* Soils reddened by the presence of oxide of iron.

† Gypsum is *sulphate* of lime—consisting of sulphuric acid (oil of vitriol) and quicklime. Carbonate of ammonia consists of carbonic acid and ammonia. When the two substances act upon each other in a moist state—the two acids change places—the sulphuric acid, as it were, *preferring* the ammonia, the carbonic acid the lime.

‡ Liebig says—"the striking fertility of a meadow on which gypsum is strewed depends *only* on its fixing in the soil the ammonia of the atmosphere, which would otherwise be volatilized with the water which evaporates."—*Organic Chemistry applied to Agriculture*, p. 86. [By *fixing* is meant the forming of *sulphate* with the ammonia. Rain water is supposed to bring down with it *carbonate of ammonia* (common smelling salts), which acts upon the *sulphate of lime* (gypsum) in such a way that *sulphate of ammonia* and *carbonate of lime* are produced. The carbonate of ammonia readily volatilizes or rises again into the air, the sulphate does not—hence the use of the word *fix*.]

When we come to consider the subject of mineral manures in general, we shall study more in detail the specific action of gypsum in promoting vegetation—a very simple calculation, however, will serve to shew that the above theory of Liebig is far from affording a satisfactory explanation of all the phenomena.

Supposing the gypsum to meet with a sufficient supply of ammonia in the soil, and that it exercises its full influence, 100 lbs. of common *unburned* gypsum will fix or form sulphate with nearly 20 lbs. of ammonia containing 16½ lbs. of nitrogen. One hundred weight, therefore, (112 lbs.) will form as much sulphate as will contain 22½ lbs. of ammonia, and if introduced without loss into the interior of plants will furnish them with 18½ lbs. of nitrogen.

1°. In the first volume of British Husbandry, pp. 322, 323, the following experiment is recorded:

Mr. Smith, of Tunstal, near Sittingbourne, top-dressed one portion of a field of red clover with powdered gypsum at the rate of five bushels (or four hundred weight*) per acre, and compared the produce with another portion of the same field, to which no manure had been

[* A ton of pure gypsum, when crushed, will yield 28 bushels. It should, however, always be applied by *weight*.]

results of experimental farming in this country are to be trusted, this is by no means the case. The action neither of this, nor probably of any other inorganic substance applied to the soil, is to be explained by a reference in *every* case to one and the *same* property only.

7°. The presence or evolution of ammonia in a soil containing animal and vegetable matter in a decaying state, induces or disposes this matter to attract oxygen from the air more rapidly and abundantly. The result of this is, that organic acid compounds are formed, which combine

applied. The first crop was cut for hay, and the second ripened for seed. The following were the comparative results per acre:

	HAY CROP.	SEED.		STRAW.		
	cwt.	*qrs.*	*lbs.*	*cwt.*	*qrs.*	*lbs.*
Gypsumed	60	3	21	22	3	12
Unmanured	20	0	20	5	0	0
Excess of produce . .	40	3	1	17	3	12

The excess of produce in all the three crops upon the gypsumed land is very large: let us calculate how much nitrogen this excess would contain. In a previous lecture (II. p. 30) it was stated as the result of Boussingault's analyses, that dry clover seed contained 7 per cent. of nitrogen, and the same experimenter found in the hay of *red clover* 1½ per cent. (or 70 and 15 lbs. respectively in 1000.)

The seed as it was weighed by Mr. Smith would still contain one-ninth of its weight of water, and, consequently, only 6⅓rd per cent. of nitrogen, [see Lecture II. p. 30.] Let it be taken at 6 per cent. and let the *straw* be supposed to contain only 1 per cent. of nitrogen, the quantity of this element being found to diminish in the grasses after the seed has ripened, and averaging 1 per cent. in the straw of wheat, oats, and barley, the weight of nitrogen reaped in the whole crop will then be as follows:

1. 40 cwt. of hay (4480 lbs.) at 1½ per cent. of nitrogen, contain 67 lbs.
2. 85 lbs. of seed at 6 per cent, contain . . . . . 5 lbs.
3. 17 cwt. 3 qrs. 12 lbs. or 2000 lbs. of straw at 1 per cent. contain 20 lbs.

Total nitrogen in the excess of crop, 92 lbs.

But, as above shewn, the five bushels or four cwt. of gypsum could fix only 90 lbs. of ammonia containing 74 lbs. of nitrogen, *leaving, therefore,* 18 *lbs. or one-fifth of the whole, to be derived from some other source.*

Now this result supposes that none of the gypsum or sulphate of ammonia was carried away by the rains, but that the whole remained in the soil, and produced its greatest possible effect on the clover—*and all in one season.*

But the effect of the gypsum does not disappear with the crop to which it is actually applied. Its beneficial action is extended to the succeeding crop of wheat, and on grass lands the amelioration is visible for a succession of years. If, then, the increased produce of a single year may contain more nitrogen than the gypsum can be supposed to yield, this substance must exercise some other influence over vegetation than is involved in its supposed action on the indefinite quantity of ammonia in the atmosphere.

2°. Again, Mr. Barnard, of Little Bordean, Hants, applied 2½ cwt. per acre on two-year old sain-foin, on a clayey soil. The increased produce of the first cutting was a ton per acre, and in October fully a ton, the undressed part yielding scarcely any hay at all, while the dressed part gave 1½ tons. The second year no gypsum was applied, and the difference is said to have been at least as great.

Supposing the increased produce in all to have been 4 tons of hay, and the nitrogen it contained to have been only one per cent.—the 4 tons (8960 lbs.) would contain about 90 lbs. of nitrogen. But 2½ cwt. would fix only 46 lbs. of nitrogen in the form of ammonia; and therefore, supposing it to have produced its maximum effect, *there remain* 44 *lbs. or nearly one half of the whole, unaccounted for by the theory.*

I would not be understood to place absolute reliance on the results of the above experiments; but the way in which such results may be easily applied for the purpose of testing theoretical views, will, I hope, convince the intelligent practical agriculturist how important it is, that the results of some of the experiments he is every year making should be accurately determined by *weight and measure.* By this means data would gradually be accumulated, on which we might hope to found more unexceptionable explanations of the phenomena of vegetation, than the results obtained in our laboratories have hitherto enabled us to advance.

In a subsequent note it will be shewn that the mode in which the nitrates of soda and potash act—in other words, the theory of their action upon vegetation—may be tested by a similar simple calculation, and the importance of precise experiments made on the farm will then still further appear. It is in the hope of inducing some of my readers to make comparative trials and publish *accurate* results, that I have introduced into the Appendix (No. I.) an outline of the mode in which such experiments may most usefully be performed.

with the ammonia, and form ammoniacal salts.* On the decomposition of these salts by lime or otherwise—the organic acids which are separated from them, are always more advanced towards that state in which they again become fit to act as food for plants.

8°. But the most interesting, and perhaps the most important property of ammonia, is one which I have already had occasion to bring under your notice, as possessed by water also, and as peculiarly fitting that fluid for the varied functions it performs in reference to vegetable life. This property is the ease with which it undergoes decomposition, either in the air, in the soil, or in the interior of plants.

In the air it is diffused through, and intimately mixed with, a large excess of oxygen gas. In the soil, especially near the surface, it is also continually in contact with oxygen. By the influence of electricity in the air, and of lime and other bases in the soil, it undergoes a constant though gradual decomposition (oxidation), its hydrogen being chiefly converted into water, and a portion of its nitrogen into nitric acid.†

In the interior of plants this and other numerous and varied decompositions in all probability take place.

The important influence which ammonia appears to exercise over the growth of plants—the evidence for which I shall presently lay before you—is only to be explained on the supposition that numerous transformations of organic substances are effected in the interior of living vegetables—which transformations all imply the separation from each other, or the *re*-arrangement of the elements of which ammonia consists. In the interior of the plant we have seen that water, ever present in great abundance, is also ever ready to yield its hydrogen or its oxygen as occasion may require, while these same elements are never unwilling to unite again for the formation of water. So it is, to a certain degree, with ammonia. The hydrogen it contains in so large a quantity is ready to separate itself from the nitrogen in the interior of the plant, and, in concert with the other organic elements introduced by the roots or the leaves, to aid in producing the different solid bodies of which the several parts of plants are made up. The nitrogen also becomes fixed in the coloured petals of the flowers, in the seeds, and in other parts, of which it appears to constitute a necessary ingredient—passes off in the form of new compounds, in the insensible perspiration or odoriferous exhalations of the plant,—or returning with the downward circulation, is thrown off by the root into the soil from which it was originally derived. Much obscurity still rests on the actual transformations which take place in the interior of plants, yet we shall be able in a future lecture, I hope, to arrive at a tolerably clear understanding of the general nature of many of them.

Such are the more important of those properties of ammonia, to which we shall hereafter have occasion to advert. The sources, remote as well as immediate, from which plants derive this, and other compounds we have described as contributing to the nourishment and growth of plants, will be detailed in a subsequent section.

* Organic *acids* generally contain more oxygen in proportion to their carbon and hydrogen, than those which are *alkaline* or *neutral*.

† It will be remembered that ammonia is represented by NH^3, water by HO, and nitric acid by NO_5. It is easy to see, therefore, how, by means of oxygen, ammonia should be converted into water and nitric acid.

§ 6. *Nitric acid, its constitution and properties.*

When the nitre or saltpetre of commerce is introduced into a retort, covered with strong sulphuric acid (oil of vitriol*) and heated over a lamp or a charcoal fire, red fumes are given off, and a transparent, often brownish or reddish liquid, distils over, which may be collected in a bottle or other receiver of glass. This liquid is exceedingly acid and corrosive. In small quantity it stains the skin and imparts a yellow colour to animal and vegetable substances. In larger quantity it corrodes the skin, producing a painful sore, rapidly destroys animal and vegetable life, and speedily decomposes and oxidizes† all organic substances. Being obtained from nitre, this liquid is called nitric acid. It consists of nitrogen combined with oxygen, one equivalent of the former (N) being united to 5 of the latter (O_5), and is represented by NO_5.

This acid contains much oxygen, as its formula indicates, and its action on nearly all organic substances depends upon the ease with which it is decomposed, and may be made to part with a portion of this oxygen.

In nature, it never occurs in a free state; but it is found in many intertropical (hot) countries in combination with potash, soda, and lime—in the state of *nitrates*. It is an important character of these nitrates that, like the salts of ammonia, they are all very soluble in water. Those of soda, lime, and magnesia attract moisture from the air, and in a damp atmosphere gradually assume the liquid form.

Saltpetre is a compound of nitric acid with potash (nitrate of potash). It is met with in the surface soil of many districts in Upper India, and is separated by washing the soil and subsequently evaporating (or boiling down) the clear liquid thus obtained. When pure, it does not become moist on exposure to the air. It is chiefly used in the manufacture of gunpowder, but has also been recommended and frequently and successfully tried by the practical husbandman, as an influential agent in promoting vegetation.

In combination with soda, it is found in deposits of considerable thickness in the district of Arica in Northern Peru, from whence it is imported into this country, chiefly for the manufacture of nitric and sulphuric acids. More recently its lower price has caused it to be extensively employed in husbandry, especially as a top-dressing for grass lands. Like the acid itself, these nitrates of potash and soda, when present in large quantities, are injurious to vegetation. This is probably one cause of the barrenness of the district of Arica in Peru, and of other countries, where in consequence of the little rain that falls, the nitrous incrustations are accumulated upon the soil. In small quantity they appear to exercise an important and salutary influence on the rapidity of growth, and on the amount of produce of many of the cultivated grasses. This salutary influence is to be ascribed, either in whole or in part, to the constitution and nature of the nitric acid which these salts contain. It

* Sulphuric acid is a compound of oxygen and sulphur, which is prepared by burning sulphur with certain precautions in large leaden chambers. It is also obtained directly by distilling *green vitriol* (sulphate of iron) at a high temperature in an iron still—hence its name *oil of vitriol*. It is a heavy, oily, acid, and remarkably corrosive liquid. In a concentrated state it is exceedingly destructive both to animal and to vegetable life.

† When a substance combines with *oxygen*, either in consequence of exposure to the air or in any other circumstances, it is said to become *oxidised*.

is chiefly with a view to the explanation I shall hereafter attempt to give of the nature of this salutary action, that I have thought it necessary here to make you acquainted with this *acid* compound of nitrogen and *oxygen*, in connection with the *alkaline* compound (ammonia) of the same gas with *hydrogen*.

Having thus shortly described both the organic elements themselves, and such chemical compounds of these elements as appear to be most concerned in promoting the growth of plants, we are prepared for entering upon the consideration of several very important questions. These questions are—

1°. From what source do plants derive the organic elements of which they are composed?

2°. In what form do plants take them up—or what proof have we that the compounds above described really enter into plants?

3°. By what organs is the food introduced into the circulation of plants? In consequence of what peculiar structure of these several parts are plants enabled to take up the compounds by which they appear to be fed; and what are the functions of these parts, by the exercise of which the food is converted and appropriated to their own sustenance and further growth?

4°. By what chemical changes is the food *assimilated* by plants, that is—after being introduced into the circulation, through what series of chemical changes does it pass, before it is converted by the plant into portions of its own substance?

5°. By what natural laws or adaptations is the supply of those compounds, which are the food of plants, kept up? Animals are supported by an unfailing succession of vegetable crops,—by the operation of what invariable laws is food continually provided for plants?

These questions we shall consider in succession.

LECTURE IV.

Source of the organic elements of plants—Source of the carbon—Form in which it enters into the circulation of plants—Source of the hydrogen—Source of the oxygen—Source of the nitrogen—Form in which nitrogen enters into the circulation of plants—Absorption of ammonia and nitric acid by plants.

THE first of the series of questions stated at the close of the preceding lecture, regards the source from which plants derive the organic elements of which they are composed. They are supported, it is obvious, at the conjoined expense of the earth and the air—how much do they owe to each, and for which elements are they chiefly and immediately indebted to the soil, and for which to the atmosphere? We must first consider the source of each element separately.

§ 1. *Source of the carbon of plants.*

We have already seen reason to believe that carbon is incapable of entering directly, in its solid state, into the circulation of plants. It is generally considered, indeed, that solid substances of every kind are unfit for being taken up by the organs of plants, and that only such as are in the liquid or gaseous state, can be absorbed by the minute vessels of which the cellular substances of the roots and leaves of plants are composed. Carbon, therefore, must enter either in the gaseous or liquid form, but from what *source* must it be derived? There are but two sources from which it can be obtained,—the soil in which the plant grows—and the air by which its stems and leaves are surrounded.

In the soil much vegetable matter is often present, and the farmer adds vegetable manure in large quantities with the view of providing food for his intended crop. Are plants really fed by the vegetable matter which exists in the soil, or by the vegetable manure that is added to it?

This question has an important practical bearing. Let us, therefore, submit it to a thorough examination.

1°. We know, from sacred history, what reason and science concur in confirming, that there was a time when no vegetable matter existed in the soil which overspread the earth's surface. The first plants must have grown without the aid of either animal or vegetable matter—that is, they must have been nourished from the air.

2°. It is known that certain marly soils, raised from a great depth beneath the surface, and containing apparently no vegetable matter, will yet, without manure, yield luxuriant crops. The carbon in such cases must also have been derived from the air.

3°. You know that some plants grow and increase in size when suspended in the air, and without being in contact with the soil.

You know, also that many plants—bulbous flower roots for example—will grow and flourish in pure water only, provided they are open to the access of the atmospheric air. Seeds also will germinate, and, when duly watered, will rise into plants, though sown in substances that contain no trace of vegetable matter.

Thus De Saussure found that two beans, when caused to vegetate in the open air on pounded flints, doubled the weight of the carbon they originally contained.

Under similar circumstances Boussingault found the seeds of trefoil increased in weight 2½ times, and wheat gave plants equal in weight, when dry, to twice that of the original grains, [Ann. de Chim. et de Phys. lxvii., p. 1.] The source of the carbon in all these cases cannot be doubted.

4°. When lands are impoverished, you lay them down to grass, and the longer they lie undisturbed the richer in vegetable matter does the soil become. When broken up, you find a black fertile mould where little trace of organic matter had previously existed.

The same observation applies to lands long under wood. The vegetable matter increases, the soil improves, and when cleared and ploughed it yields abundant crops of corn.

Do grasses and trees derive their carbon from the soil? Then, how, by their growth, do they increase the quantity of carbonaceous matter which the soil contains? It is obvious that, taken as a whole, they must draw from the air not only as much as is contained in their own substance, but an excess also, which they impart to the soil.

5°. But on this point the rapid growth of peat may be considered as absolutely conclusive. A tree falls across a little running stream, dams up the water, and produces a marshy spot. Rushes and reeds spring up, mosses take root and grow. Year after year new shoots are sent forth, and the old plants die. Vegetable matter accumulates; a bog, and finally a thick bed of peat is formed.

Nor does this peat form and accumulate at the expense of one species or genus of plants only. Latitude and local situation are the circumstances which chiefly effect this accumulation of vegetable matter on the soil. In our own country, the lowest layers of peat are formed of aquatic plants, the next of mosses, and the highest of heath. In Terra del Fuego, "nearly every patch of level ground is covered by two species of plants (*astelia pumila* of Brown, and *donatia magellanica*), which, by their joint decay, compose a thick bed of elastic peat." "In the Falkland Islands, almost every kind of plant, even the coarse grass which covers the whole surface of the island, becomes converted into this substance."*

Whence have all these plants derived their carbon? The quantity originally contained in the soil is, after a lapse of years, increased ten thousand fold. Has dead matter the power of reproducing itself? You will answer at once, that all these plants must have grown at the expense of the air, must have lived on the carbon it was capable of affording them, and as they died must have left this carbon in a state unfit to nourish the succeeding races.

This reasoning appears unobjectionable, and, from the entire group of facts, we seem justified in concluding that plants every where, and under all circumstances, derive the whole of their carbon from the atmosphere.

* *Darwin's Researches in Geology and Natural History*, pp. 349-50. Dr. Gerville informs me that the *astelia* approaches more nearly to the *juncus* or *rush tribe*, and the *donatia* to our tufted saxifrages, than to any other British plants.

In certain extreme cases, as in those of plants growing in the air and in soils perfectly void of organic matter, this conclusion must be absolutely true. The phenomena admit of no other interpretation. But is it as strictly true of the more usual forms of vegetable life, or in the ordinary circumstances in which plants grow spontaneously or are cultivated by the art of man? Has the vegetable matter of the soil no connection with the growth of the trees or herbage?—does it yield them no regular supplies of nourishment? Does nature every where form a vegetable mould on which her wild flowers may blossom and her primeval forests raise their lofty heads? Has the agricultural experience of all ages and of all countries led the practical farmer to imitate nature in preparing such a soil? Does nature work in vain?—is all this experience to be at once rejected?

While we draw conclusions, legitimate in kind, we must be cautious how, in degree, we extend them beyond our premises.

The consideration of one or two facts will shew that our general conclusion must either be modified or more cautiously expressed.

1°. It is true that plants will, in certain circumstances, grow in a soil containing no sensible quantity of organic matter—but it is also true, *generally*, that they do not luxuriate or readily ripen their seed in such a soil.

2°. It is consistent with almost universal observation, that the same soil is more productive when organic matter is present, than when it is wholly absent.

3°. That if the crop be carried off a field, less organic matter is left in the soil than it contained when the crop began to grow, and that by constant cropping the soil is gradually exhausted of organic matter.

Now it must be granted that tillage alone, without cropping, would gradually lessen the amount of organic matter in the soil, by continually exposing it to the air and hastening its decay and resolution into gaseous substances, which escape into the atmosphere. But two years' open fallow, with constant stirring of the land, will not rob it of vegetable matter so effectually as a year of fallow succeeded by a crop of wheat. Some of the vegetable matter, therefore, which the soil contained when the seed was sown, must be carried off the field in the crop.

The conclusion therefore seems to be reasonable and legitimate, that the crop which we remove from a field has not derived all its carbon directly from the air—but has extracted a portion of it immediately from the soil. It is to supply this supposed loss, that the practical farmer finds it necessary to restore to the land in the form of manure—among other substances—the carbon also of which the straw or hay had robbed the soil.

But how is this reconcileable with our previous conclusion, that the whole of the carbon is derived from the air? The difficulty is of easy solution.

A seed germinates in a soil in which no vegetable matter exists; it sprouts vigorously, increases then slowly, grows languidly at the expense of the air, and the plant dies stunted or immature. But in dying it imparts vegetable matter to the soil, on which the next seed thrives better—drawing support not only from the air, but by its roots from the soil also. The death of this second plant enriches the soil further, and thus,

while each succeeding plant is partly nourished by food from the earth, yet each, when it ceases to live, imparts to the soil all the carbon which during its life it has extracted from the air. Let the quantity which each plant thus returns to the soil, exceed what it has drawn from it by only one ten-thousandth of the whole, and—unless other causes intervene—the vegetable matter in the soil must increase.

Thus while it is strictly true that the carbon contained in all plants has *been originally* derived from the air, it is not true that the *whole* of what is contained in any one crop we raise, is *directly* derived from the atmosphere—the proportion it draws from the soil is dependent upon numerous and varied circumstances.

The history of vegetable growth, therefore—in so far at least as the increase of the carbon is concerned—may be thus simply stated:

1°. A plant grows partly at the expense of the soil, and partly at that of the air. When it reaches maturity, or when winter arrives, it dies. The dead vegetable matter decays, a part of it is resolved into gaseous matter and escapes into the air, a part remains and is incorporated with the soil. If that which remains be greater in quantity than that which the plant in growing derived from the soil, the vegetable matter will increase; if less, it will diminish.

2°. In warm climates the decay of dead vegetable matter is more rapid, and, therefore, the portion left in the soil will be less than in more temperate regions—in other words, the vegetable matter in the soil will increase less rapidly—it may not increase at all.

3°. As we advance into colder countries, the decay and disappearance of dead vegetable matter, in the form of gaseous substances which escape into the atmosphere, become more slow—till at length, between the parallels of 40° and 45°, it begins to accumulate in vast quantities in favourable situations, forming peat bogs of greater or less extent. While the living plant here, as in warm climates, derives carbon both from the earth and from the air, the dead plant, during its slow and partial decay, restores little to the atmosphere, and therefore adds rapidly to the vegetable matter of the soil.

4°. Again, in one and the same climate, the decay of vegetable matter, and its conversion into gaseous substances, is more rapid in proportion to the frequency with which it is disturbed or exposed to the action of the sun and air. Hence this decay may be comparatively slow in shady woods and in fields covered by a thick sward of grass; and in such situations organic matter may accumulate, while it rapidly diminishes in an uncovered soil, or in fields repeatedly ploughed and subjected to frequent cropping.*

Being thus fitted, by nature, to draw their sustenance—now from the earth, now from the air, and now from both, according as they can most readily obtain it—plants are capable of living,—though rarely a robust life,—at the expense of either. The proportion of their food which they actually derive from each source, will depend upon many circumstances—on the nature of the plant itself—on the period of its growth—on the soil in which it is planted—on the abundance of food presented to

* In removing a crop we take away both what the plants have received from the earth and what they have absorbed from the air—the materials, in short, intended by nature to restore the loss of vegetable matter arising from the natural decay.

either extremity—on the warmth and moisture of the climate—on the duration and intensity of the sunshine, and other circumstances of a similar kind—so that the only general law seems to be, that, like animals, plants have also the power of adapting themselves, to a certain extent, to the conditions in which they are placed; and of supporting life by the aid of such sustenance as may be within their reach.

Such a view of the course of nature in the vegetable kingdom, is consistent, I believe, with all known facts. And that the Deity has bountifully fitted the various orders of plants—with which the surface of the earth is at once beautified and rendered capable of supporting animal life—to draw their nourishment, in some spots more from the air, in others more from the soil, is only in accordance with the numerous provisions we everywhere perceive, for the preservation and continuance of the present condition of things.

By taking a one-sided view of nature, we may arrive at startling conclusions—correct, if taken as partial truths, yet false, if advanced as general propositions—and fitted to lead into error, such as have not the requisite knowledge to enable them to judge for themselves—or such as, doubtful of their own judgment, are willing to yield assent to the authority of a name.

Of this kind appears, at first sight, to be the statement of Liebig, that "when a plant is quite matured, and when the organs by which it obtains food from the atmosphere are formed, the carbonic acid of the soil is no further required"—and that, "during the heat of summer it derives its carbon exclusively from the atmosphere."—[Organic Chemistry applied to Agriculture, p. 48.]

A little consideration will shew us that, while the proposition contained in the former quotation may be entertained and advanced as a *matter of opinion*—the latter is obviously incorrect. In summer, when the sun shines the brightest, and for the greatest number of hours, the evaporation from the leaves of all plants (their insensible perspiration) is the greatest—the largest supply of water, therefore, must at this season be absorbed by the roots, and transmitted upwards to the leaves.—[Lindley's Theory of Horticulture, p. 46.]—But this water, before it enters the roots, has derived carbonic acid and other soluble substances from the air and from the soil, in as large quantity at this period as at any other during the growth of the plant; and these substances it will carry with it in its progress through the roots and the stem.

Are the functions of the root changed at this stage of the plants' growth? Do they now absorb pure water only, carefully separating and refusing to admit even such substances as are held in *solution?* Or do the same materials which minister to the growth of the plant in its earlier stages, now pass upwards to the leaf and return again in the course of the circulation unchanged and unemployed, to be again rejected at the roots? Does all this take place in the height of summer, while the plant is still rapidly increasing in size? The opinion is neither supported by facts nor consistent with analogy.

But such an opinion,—however the words above quoted may mislead some,—is not intended to be advanced by Liebig; for, in the following page he says, that "the power which roots possess of taking up nourishment does not cease so long as nutriment is present." In summer,

therefore, as well as in spring or in autumn, the plant must be ever absorbing nourishment by these roots, if the soil is capable of affording it—and thus, in the general vegetation of the globe, the increase of carbon in growing plants must, at every season of the year, be partly derived from the vegetable matter of the soil in which they grow.

§ 2. *Form in which carbon enters into the circulation of plants.*

Supposing it to be established that the whole of the carbon contained in plants has originally been derived from the air—we have only to inquire in what state this element exists in the atmosphere, in order to satisfy ourselves as to the *form* of combination in which it is and has been received into the circulation of plants. In considering the constitution of the atmosphere in the preceding lecture, it was stated that carbonic acid, a compound of carbon and oxygen, is always present in it—and that, though this gas is diffused through the air in comparatively small quantity only, yet it is everywhere to be detected,—while no other compound of carbon is to be found in it in any appreciable quantity. We must conclude, therefore, that from this gaseous carbonic acid the whole of the carbon contained in plants has been *primarily* derived. This conclusion is confirmed by the observation so frequently made, that the leaves of plants in sunshine absorb carbonic acid, and that plants die in an atmosphere from which this gas is entirely excluded.

But we have seen reason to believe that, under existing circumstances, plants also extract a portion of the carbon they contain from the soil in which they grow. In what state or form of combination do the *roots* absorb carbon?

The most abundant product of the decay of vegetable matter in the soil, is the same carbonic acid which plants inhale so largely from the atmosphere by their leaves. In a soil replete with vegetable matter, therefore, the roots are surrounded by an atmosphere more or less charged with carbonic acid. Hence if they are capable of inhaling gaseous substances, this gas will enter the roots in the aeriform state—if not, it must enter in solution in the water, which the roots drink in so largely, to supply the constant waste caused by the insensible perspiration of the leaves.

During the early fermentation of artificial manures there is also developed in the soil a variable proportion of light carburetted hydrogen (Lecture III., p. 49), which is supposed by some to enter occasionally into the roots. That it does enter, however, is doubtful,—and we are safe, I think, in considering this compound not only as an uncertain source of the carbon of plants, but as one from which, in the most favourable circumstances, they can derive only a small supply.

Thus, from the earth as from the air, the most unfailing supply of food is the gaseous carbonic acid.

But as the water passes through the soil it takes up inorganic substances—potash, soda, lime, magnesia—and conveys them through the roots into the circulation of the plants. Can it refuse to take up and to perform a similar office to the soluble organic substances it meets with, as it sinks through the soil? Or do the spongioles of the roots keep a perpetual watch over the entering waters, to prevent the introduction of every soluble form of carbon but that of carbonic acid? Or, supposing such

substances introduced into the interior of the plant, are none of them *digested* there and converted to the general purposes of food? A statement of two or three facts will afford a satisfactory reply to these several questions.

1°. When plants are made to grow in infusions of madder the radicle fibres are tinged of a red colour.

2°. The flower of a white hyacinth becomes red after a few hours, when the earth in which it is planted is sprinkled with the juice of the *phytolaca decandra* (Biot).

Therefore organic substances can enter into the roots, and thence into the circulation, of the plant.

3°. The colour of the madder does not usually extend upwards to the leaves and flowers of the plant.

4°. The colour imparted to the flower of the white hyacinth disappears in the sunshine in the course of a few days.

Organic colouring matters, therefore, undergo a chemical change either in the stem, in the leaf, or in the flower—some sooner, some later—and the same is probably the case with most other organic substances which gain admission into the interior of plants.

5°. Sir Humphry Davy introduced plants of mint into weak solutions of sugar, gum, jelly, the tanning principle, &c., and found that they grew vigorously in all of them. He then watered separate spots of grass with the same several solutions, and with common water, and found all to thrive more than that to which common water was applied—while those treated with sugar, gum, and gelatine grew luxuriantly.—[Davy's Agricultural Chemistry, Lecture VI.]

Therefore different organic substances—being introduced into the circulation and there changed—are converted by plants into their own substance, or *act as food, and nourish the plant.*

We may consider it, therefore, to be satisfactorily established that, while a plant sucks in by its leaves and roots much carbon in the form of carbonic acid, it derives a *variable* portion of its immediate sustenance (of its carbon) from the soluble organic substances that are within reach of its roots.

This fact is never doubted by the practical husbandman. It forms the basis of many of his daily and most important operations, while the results of these operations are further proofs of the fact.

The nature of the soluble substances which are formed during the decay of animal and vegetable substances—and which the roots of plants are supposed to take up—will be considered in a subsequent lecture.*

§ 3. *Source of the hydrogen of plants.*

The source of the hydrogen of plants is less doubtful, and will require less illustration, than the source of the carbon. This elementary substance is not known to exist in nature in an uncombined state, and, therefore, it must, like carbon, enter into plants in union with some other element.

1°. Water has been already shewn to consist of hydrogen in combina-

* This part of the subject might have been discussed here without appearing out of place—but it will come in more appropriately, I think, when treating of the nature and mode of action of *vegetable manures*.

tion with oxygen. In the form of vapour, this compound pervades the atmosphere, and plays among the leaves of plants, while in the liquid state it is diffused through the soil, and is unceasingly drunk in by the roots of all living vegetables. In the interior of plants—at least during their growth—this water is continually undergoing decomposition, and it is unquestionably the chief source of the hydrogen which enters into the constitution of their several parts. In explaining the properties of water I have already dwelt upon the apparent facility with which its elements are capable either of separating from, or of *re*-uniting to, each other, in the vascular system of animals or of plants. The reason and precise results of these transformations we shall hereafter consider.

2°. In light carburetted hydrogen (CH_2), given off as already stated during the decay of vegetable matter, and said to be always present in highly manured soils, this element, hydrogen, exists to the amount of nearly one-fourth of its weight. On the extent, therefore, to which this gaseous compound gains admission into the roots of plants, will depend the supply of hydrogen which they are capable of drawing from this source. Had we satisfactory evidence of the actual absorption of this (marsh) gas by the roots or *leaves* of plants, in any quantity, we should have no difficulty in admitting that plants might, from this source, easily obtain a considerable supply both of carbon and of hydrogen. It would be also easy to explain how (that is, by what chemical changes,) it is capable of being so appropriated. But the extent to which it really acts as food to living vegetables is entirely unknown.

3°. Ammonia is another compound, containing much hydrogen, [its formula being NH_3, or one equivalent of nitrogen and three of hydrogen,] which, as I have already stated, exercises a manifest influence on the growth of plants. If this substance enter into their circulation in any sensible quantity,—if, as some maintain, it be not only universally diffused throughout nature, but is constantly affecting, and influencing at all times, the universal functions of vegetation—there can be no doubt that the hydrogen it contains must, to an equal extent, be concerned in the production of the various organic substances which are formed or elaborated by the agency of vegetable life. How far this probable interference of the hydrogen of ammonia with the functions of the vegetable organs, will tend to explain or illustrate the influence actually exerted by this compound, we shall, by and by, more accurately inquire. In the mean time, the quantity of ammonia, which actually enters into the circulation of plants in a state of nature, is too little known, and making the largest allowance, probably too minute, to permit us to consider it as an important source of hydrogen to the general vegetation of the globe.

4°. The soluble organic substances, which enter into the circulation of plants through the roots, as shewn in the preceding section, do not consist of carbon and water only, but of combinations of carbon with hydrogen and oxygen in various proportions. From these substances, therefore, plants derive an uncertain and indefinite supply of hydrogen in a state already half-organized, and probably still more easily assimilated or converted into portions of their own substance, than when this element is combined with oxygen in the form of water.

We may, therefore, conclude generally in regard to the source of the hydrogen of plants—that though there are undoubtedly several other

forms of combination in which this element may enter into their circulation, in uncertain quantity—yet that all-pervading water is the main and constant source from which the hydrogen of vegetable substances is derived.

§ 4. *Source of the oxygen of plants.*

We can at once perceive, and without difficulty, the various sources of the oxygen of plants; though it is difficult in this case also to say how much they derive from each.

1°. The water which they imbibe so largely consists in great part of oxygen, and is easily decomposed, [eight-ninths of the weight of water are oxygen.] This alone would yield an inexhaustible supply.

2°. The atmosphere contains 21 per cent. of its bulk of oxygen, and the leaves of plants in certain circumstances are known to absorb this oxygen. The air in which they live, therefore, might be another source.

3°. Carbonic acid contains 72 per cent. by weight of oxygen, and this gas is also known to be absorbed in large quantity from the atmosphere by the leaves of plants—while its solution in water is admitted readily by the roots.

From any one of these sources an ample supply of oxygen might readily be obtained, and it may be considered as a proof of the vast importance of this element to the maintenance of animal and vegetable life, that it is everywhere placed so abundantly within the reach of living beings. It is from the first of these sources, however, from the water they contain, that plants are believed to derive their principal supply. The reasons on which this opinion is founded will appear when we shall have considered the functions of the several parts of plants, and the chemical changes to which the food is subjected in the course of the vegetable circulation.

§ 5. *Source of the nitrogen of plants.*

The quantity of nitrogen present in plants is very small, compared with that of any of the other elements which enter into their constitution. Of this you will be reminded, by a reference to the analyses of hay, oats, and potatoes, exhibited in the second lecture (page 30), which shew that the nitrogen contained in these several crops, when perfectly dried at 240° F., is respectively $1\frac{1}{3}$, $2\frac{1}{3}$, and $1\frac{1}{4}$ per cent. In the state in which they are usually given to cattle they contain a still less per centage of nitrogen, in consequence of the quantity of water still present in them. Thus raw potatoes as they are given to cattle contain only $\frac{1}{3}$ of a per cent. of nitrogen, hay $1\frac{1}{3}$ per cent., and oats $1\frac{9}{10}$* per cent., or a hundred pounds of each contain 5 ounces, 1 pound 5 ounces, and 1 pound 14 ounces respectively.

It would appear at first sight as if this small quantity of nitrogen could be of little importance to the plant, especially since, as we shall hereafter see, it does not enter as a constituent into those vegetable substances, such as woody fibre, starch, sugar, and gum, which plants produce in the greatest abundance, and of which their own stems and

* 0·33, 1·29, and 1·87 per cent.—the potatoes containing also 72 per cent. of water, the hay 14, and the oats 15 per cent.

branches chiefly consist. The same remark, however, applies to this, as to many other cases which present themselves to the chemist, during his analyses, especially of organized substances,—that those elements which are present only in small quantity are as necessary—as essential—to the constitution of the particular substance in which they occur, as other elements are of which they contain much; and that if these small quantities are removed or absent, not only are the physical and chemical properties of the substance materially altered, but it is found also to exercise a very different influence on animal and vegetable life. This latter observation will present itself to you in a very striking light, when we come hereafter to study the nutritive properties of the several kinds of food by which animals are chiefly supported,—and shall see on what elementary body their relative nutritive properties depend, or by the amount of which their relative value appears at least to be indicated.

But a consideration of the absolute quantity of nitrogen contained in an entire crop will satisfy you that though small in comparative amount, [that is, compared with the carbon and oxygen which plants contain,] this element cannot be without its due share of importance in reference to vegetable life. Hay, as above stated, contains, as it is stacked, $1\frac{1}{2}$* per cent. of nitrogen, or a ton of hay contains 30 lbs. of this element. A good crop of hay, on land which is depastured during the winter, will amount to 2 or $2\frac{1}{2}$ tons† per acre. Taking 2 tons as an average, the hay from one acre will contain 60 lbs. of nitrogen, or from 100 acres 6000 lbs., equal to $2\frac{2}{3}$ tons of nitrogen.

Allowing, therefore, nothing for the aftermath, and supposing the other crops to contain no more nitrogen than the hay does, the farmer of five hundred acres will annually carry into his stack-yard at least 13 tons of nitrogen in the form of hay, straw, grain, and other produce.‡

Nature performs all her operations on a large scale, and the quantity of materials she employs are large in a corresponding degree. Hence, though *comparatively* small, the nitrogen in vegetable substances is *absolutely* large. You cannot suppose, when viewed in this light, that nitrogen is an element of little consequence in reference to vegetable life; or that in nature it should be so constantly and universally diffused without reference to some important end. If I may be allowed a familiar illustration of the mode in which small quantities of matter will affect the sensible properties of large masses, I would recall to your minds the effects of seasoning upon food, in imparting, when added in small quantity only, an agreeable relish to what would otherwise be

* In different crops of hay *Boussingault* found in three several years the following proportions of nitrogen:—

	Hay, as commonly stacked.	Hay dried at 230° F.	
In 1836	1·18	1·04 of nitrogen per cent.	
" 1838	1.3	1·15	" "
" 1839	1·5	1·3	" "
Aftermath	2·4	2 0	" "

† The Rev. Mr. Ogle, of Kirkley, Northumberland, informs me that some of his land near the Hall has yielded annually at this rate for 100 years, and without other manure than the droppings from the cattle which have fed upon it.

‡ This *average* estimate gives but an inaccurate idea of the quantity actually contained in some species of crops. Thus red clover with the aid of gypsum will yield 3 tons of hay per acre. This hay contains more than twice the quantity of nitrogen (Boussingault) that common hay does, hence an acre of such hay would contain at least 180 lbs. of nitrogen. (See Lecture II., p. 30.)

insipid. But I need not dwell on this point, since I shall hereafter have occasion to draw your attention to certain facts in reference to the constitution of the atmosphere, which will satisfy you that, by the agency of *comparatively* feeble causes, gigantic effects are continually produced in nature,—and that we can scarcely fall into a graver error in reasoning of natural processes, than by overlooking the agency of forms of matter which present themselves to our senses in minute quantity only. In reference to insect life this truth has been long established. In the coral reefs you are familiar with the wonderful results of the persevering labour of minute animals in one element. When I come to explain the nature and origin of soils, I shall have occasion to show that even the element on which you labour—the earth, on the cultivation of which your thoughts and hands are daily employed—is occasionally indebted for some of its most valuable properties to a similar agency, often unseen by you, and though working for your good, unheeded and unthought of.

Whence, then, is this nitrogen derived by plants? The *primary* source it is not difficult to see. We can arrive at it by a train of reasoning similar to that which led us to the atmosphere as the original source of the carbon of plants. Nitrogen does not constitute an *ingredient* of any of the solid rocks,* nor do we know any other source than the atmosphere from which it can be obtained in very large quantity. It exists, as we have seen, in many vegetables, and it is more largely present in animal substances, but these organized matters must themselves have drawn this element from a foreign source, and the atmosphere is the only one from which we can fairly assume it to have been originally derived.

But though the nitrogen, like the carbon of plants, may thus be traced to the atmosphere—as its orginal source—it does not follow that this element is either absorbed *directly* from the air, or, in an uncombined and gaseous state. Though the leaves of trees and herbs are continually surrounded by nitrogen, the constitution of plants may be unfitted for absorbing it by their leaves. The nitrogen may not only require to be in a state of combination before it can enter into the circulation, but it may also be capable of gaining admission only by the roots. These points are considered in the following section.

§ 6. *Form in which the nitrogen enters into the circulation of plants.*

The question as to the form in which nitrogen enters into the circulation of plants is one which at the present moment engages much attention. It will be proper, therefore, to discuss it with considerable care.

1°. It is considered an essential part of good tillage to break up and loosen the soil, in order that the air may have access to the dead vegetable matter, as well as to the living roots which descend to considerable depths beneath the surface. When thus admitted to the roots, it is impossible that some of the nitrogen of the atmosphere, as well as some of its oxygen, may be directly absorbed and appropriated by the plant. To what extent this absorption of nitrogen may proceed, however, we

* Except coal, and coal itself is of vegetable origin. Throughout all rocks in which organic remains are found, more or less animal matter containing nitrogen is to be met with, but these remains are only accidentally present, and they must have derived their nitrogen during life, either directly or indirectly, from the atmosphere.

have as yet no experimental results from which we can form any estimate. Whether it takes place at all or not, is wholly a matter of opinion.

2°. The leaves of plants, as will be more fully explained hereafter, absorb certain gaseous substances from the atmosphere, and we might, therefore, expect that some of the nitrogen of the air would, by this channel, be admitted into their circulation. This view, however, is not confirmed by any of the experiments hitherto made with the view of investigating the action and functions of the leaves.* We are not at liberty, therefore, to assume that any of the nitrogen which plants contain has in this way been derived directly from the air. It may be the case; but it is not yet proved.

3°. There is little doubt, however, that nitrogen enters the roots of plants in a state of solution. But the quantity they thus absorb is uncertain—it is supposed to be small, and must be variable.

When water is exposed to the air in an open vessel it gradually absorbs oxygen and nitrogen, though, as has been stated in a previous lecture, in proportions different from those in which they exist in the atmosphere. The whole quantity of the mixed gases thus taken up amounts to about 4 per cent. of the bulk of the water (Humboldt and Gay-Lussac), and in rain water about $\frac{2}{3}$ of the whole consist of nitrogen. One hundred cubic inches of rain water, therefore, will carry into the soil about $2\frac{2}{3}$ inches of nitrogen gas. But in passing through the soil, the water meets with other soluble substances before it reaches the roots, especially the deep-seated roots of plants. It takes up carbonic acid, and it dissolves solid substances, and in doing so it is a property of water to give off a portion of the other gases which it had previously absorbed from the air.

But let us suppose that rain water actually takes to the roots, and carries with it into the circulation of the plant, 2 per cent. of its bulk of nitrogen, and let us calculate how much of the nitrogen it contains a crop of hay could in this way derive from the air.

* See subsequent lecture "*On the structure and functions of the several parts of plants.*" The experiments above referred to were made upon plants growing in close vessels, the air contained in which was measured and examined (analysed) both before the plants were introduced and after they had been some time in the vessel. In these experiments the bulk of the nitrogen present has sometimes been observed to increase, but *never to diminish*, in quantity. The conclusion seems satisfactory, that no nitrogen is abstracted directly from the atmosphere by the leaves of plants. Yet Boussingault[1] very justly remarks, that a diminution in the bulk of the nitrogen too small to be detected in the ordinary mode of making these experiments, would be sufficient to account for a considerable portion of that comparatively small quantity of nitrogen which is present in all living plants. While, therefore, we accord their due weight to these researches of the vegetable physiologists, we are not to consider them as by any means decisive of the question. With this rational and cautious conclusion, Liebig is not satisfied; he says, "We have not the slightest reason for believing that the nitrogen of the atmosphere takes part in the processes of assimilation of plants and animals; on the contrary, we know that many plants emit the nitrogen which is absorbed by their roots either in the gaseous form or in solution in water." (p. 70.) But if they occasionally expire nitrogen by their leaves, why must this nitrogen be exactly that portion which has previously been absorbed by the roots in the uncombined state, and the quantity of which is so uncertain and so indefinite?

[[1] Boussingault details a series of experiments in the course of which he made peas, trefoil, wheat, and oats, grow in the same pure siliceous sand containing no organic matter, and watered them with the same distilled water. The absolute quantity of nitrogen increased sensibly in the peas and trefoil during their growth; in the wheat and oats no change could be detected by analysis. From these results he is inclined to infer that the green leaves of the former have the power of *sensibly* absorbing nitrogen from the atmosphere, while those of the latter have not this power—at least under the circumstances in which the experiments were made. This conclusion, however, is not *certain*, as will presently be shewn.—See *Ann. de Chim. et de Phys.* lxvii. p. 1, and lxix. p. 353.]

The quantity of rain that falls at York from the first of March to the middle of June—during which time the grass grows and generally ripens—is about five inches.* On a square foot, therefore, there fall 720 cubic inches of water, containing 2 per cent. of their bulk, or 14 cubic inches of nitrogen, weighing 4¼ grains. This gives 28 lbs. for the quantity of nitrogen thus brought to the soil over an entire acre. But if we consider how the rain falls in our climate, we cannot suppose the grass in a field to absorb by its roots, and afterwards perspire by its leaves, more than one-third of the whole. This quantity would carry with it 9 lbs. of nitrogen into the circulation of the plants—or little more than a seventh part of the 60 lbs. which, as we have seen, are taken off the field in a crop of hay.

Such a calculation as this affords at the best but a very rude approximation to the truth—it seems, however, to justify us in concluding that plants can derive from the air, and in an uncombined state, only a small portion of the nitrogen they are found to contain—and that they probably draw a larger supply from certain *compounds* of this elementary substance with hydrogen and oxygen—which are known to come within the reach of their roots and leaves.

The most important of these compounds, and those perhaps the most extensively concerned in influencing vegetation, are ammonia and nitric acid, the properties of which have been described in the preceding lecture.†

§ 7. *Absorption of ammonia by plants.*

That ammonia enters directly into the circulation of plants is rendered probable by a variety of considerations.

1°. Thus it is found to be actually present in the juices of many plants. In that of the beet-root, and in those of the birch and maple trees, it is associated with cane sugar (Liebig.) In the leaves of the tobacco plant, and of scurvy grass, in elder flowers, and in many fungi, it is in combination with acid substances, and may be detected by mixing their juices with quick-lime.—[Schübler *Agricultur Chemie*, II., p. 56.]

2°. Some plants actually perspire ammonia. Among these is the *Chenopodium Olidum* (stinking goosefoot), which is described by Sir William Hooker as "giving out a most detestable odour, compared to putrid salt fish." In the odoriferous matter given off ammonia is contained, and may be detected by putting a glass shade over the plant, and after a time introducing a feather moistened with vinegar or dilute muriatic acid.—[Chevalier *Jour. de Pharm.* X., p. 100.] It is also present in the odoriferous exhalations of many sweet-smelling plants and flowers.—[Schübler, I., p. 152.]

3°. Nearly all vegetable substances, when distilled with water, yield an appreciable quantity of ammonia. Thus the leaves of hyssop, and

* The result of experiments made in 1834 by Prof. Phillips and Mr. Edward Gray. The mean annual fall of rain at York is about 22 inches.—(See fifth Report of the British Association, p. 173.)

† It will be recollected that ammonia consists of one equivalent of nitrogen (N) united to three of hydrogen (H_3), being represented by NH_3; and that nitric acid consists of one of nitrogen (N) and five of oxygen (O_5), its formula being NO_5.—See Lecture III., p 34.

the flowers of the lime tree, yield distilled waters in which ammonia can be detected (Schübler), the seeds of plants thus distilled yield it in abundance (Gay-Lussac), and traces of it may be found in most vegetable extracts (Liebig).

4°. Ammonia is also given off, among other products, when wood is distilled in iron retorts for the manufacture of pyroligneous acid, and by a similar treatment it may be obtained from many other vegetable substances.

The above facts, however, are not to be considered as *proofs* that ammonia enters directly into the circulation of plants either by their roots or by their leaves. That which is associated with sugar in the beet, may have been formed by the same converting power which, in the interior of the plant, has produced the sugar from carbonic acid and water. So, that exhaled by the leaves of the goosefoot, which grows in waste places, especially near the sea, may have been produced during the upward flow of the sap or during its passage over the leaf. And we *know* that the nitrogen does not exist in the state of ammonia in the seeds of plants, or in wood, or in coal—though from all of them it may be obtained by the processes above described.

The production of ammonia, by the agency of a high temperature, may be illustrated by a very familiar experiment often performed, though for a very different purpose. The juice and dried leaf of tobacco contain nitre (nitrate of potash) and a *little* ammonia. But when tobacco is burned, ammonia in sensible quantity is given off along with the smoke, chiefly in the state of carbonate of ammonia. This may be shown by bringing a lighted cigar near to reddened litmus paper, when the blue colour will be restored; or to a red rose, when the leaves will become green; or to a rod dipped in vinegar or in dilute muriatic acid, when a white cloud will appear.—[Runge, *Einleitung in die technische Chemie*, p. 375.]

In this case a portion of the ammonia given off by the tobacco has most probably been formed during the combustion, at the expense of the nitrogen contained in the nitrate of potash which is present in the leaf.

5°. But there are other circumstances which are strongly in favour of the opinion, that ammonia not unfrequently does enter, as such, into the circulation of plants.

Thus it is proved, by long experience, that plants grow most rapidly and most luxuriantly when supplied with manure containing substances of animal origin. These substances are usually applied to the roots or leaves in a state of fermentation or decay, during which they always evolve ammonia. Putrid urine and night-soil are rich in ammonia, and they are among the most efficacious of manures. This ammonia is *supposed* to enter into the circulation of plants along with the water absorbed by their roots, and sometimes even by the pores of their leaves. We can scarcely be said to have as yet obtained decisive proof that it does so enter, but probabilities are strongly in favour of this supposition; and when we come hereafter to consider minutely the mode in which it is likely to act, when within the plant, we shall find the probabilities derived from practical experience to be strengthened by the deductions of theory.

But though the facts so long observed in reference to the action of am-

imal manures upon vegetation, justify us in believing that ammonia actually enters into the roots, and perhaps into the leaves, of plants—we ought not hastily to conclude that all the nitrogen which plants are capable of deriving from decaying animal matter *must* enter into their circulation in the form of ammonia. Other soluble compounds containing nitrogen are formed during the decay of animal substances—they actually exist largely in the liquid manures of the stable and fold-yard, and they can scarcely fail, when applied to the soil, to be to a certain extent absorbed by the roots of plants. This *urea* is a substance containing much nitrogen, which exists in the urine or excrements of most animals, and by its decomposition produces carbonate of ammonia. But being very soluble, this substance may enter directly into the roots, and may be there decomposed, and made to give up its nitrogen to the living plant. To other compound substances of animal origin the same observation may apply,*—so that while the fact, that animal manure in a state of fermentation is very beneficial to vegetation, may be considered as rendering it highly probable that the ammonia which such manure contains, enters directly and supplies much nitrogen to the growing plants, it must not be entirely left out of view that, in nature, a portion of the nitrogen, derived from animal substances, may be obtained immediately from other compounds in which ammonia does not exist.

To what *amount* ammonia actually enters into the circulation of plants, or how much of the nitrogen they contain it actually supplies, we have no means of ascertaining. Were it abundantly present in the soil, its great solubility would enable it to enter, with the water absorbed by the roots, in almost unlimited quantity. In a subsequent section we shall consider the conditions under which ammonia is produced in nature, the comparative abundance in which it exists on the earth's surface, and the extent of the influence it may be supposed to exercise on the general vegetation of the globe.

§ 8. *Absorption of nitric acid by plants.*

1°. That ammonia is actually present in the juices of many living vegetables has been adduced, as a kind of presumptive evidence, that this compound is directly absorbed by plants. A similar presumption is offered in favour of the direct entrance of nitric acid, by its invariable presence in combination with potash, soda, lime, or magnesia, in the juices of certain common and well known plants. Thus it is said to be always contained in the juices of the tobacco plant, of the sunflower, of the goosefoot,† and of common borage. The nettle is also said to contain it, and it has been detected in the grain of barley.‡ It exists probably in the juices of many other plants in which it has not hitherto

* Thus it may be applied more strongly to the *hippuric acid*, which exists in the urine of the horse, and other herbivorous animals. This acid decomposes naturally into *benzoic acid* and ammonia. The sweet-scented vernal-grass (*Anthoxanthum Odoratum*) by which hay is perfumed, owes its agreeable odour to the presence of this *benzoic acid*. It may, therefore, be supposed that, where cattle and horses graze, the grasses actually absorb the *hippuric* acid contained in the urine, which reaches their roots, decompose it as it ascends with the sap, appropriate its nitrogen, and exhale the odoriferous benzoic acid.

† *Chenopodium*, probably in all the species of this genus.—See Liebig, p. 82.

‡ Grisenthwaite (*New Theory of Agriculture*, p. 105) says, it is always present in barley in the form of nitrate of soda.—*See Appendix.*

been sought for. Were we, therefore, entitled, from the mere presence of this acid in plants, to infer that it had really entered by their roots or leaves, we should have no hesitation in drawing our conclusion. But, like ammonia, it may have been formed in the interior of the living vegetable;* and hence the fact of its presence proves nothing in regard to the state in which the nitrogen it contains entered into the circulation of the plant.

2°. But nitric acid, like ammonia, exerts a powerful influence on the growing crop, whether of corn or of grass. Animal matters, as we have seen, give off ammonia during their decay, and manures are rich and efficacious in proportion to the quantity of animal manure they contain. The crop produced also is valuable and rich in nitrogen in like proportion. Therefore, as already stated, it is inferred that ammonia enters directly into the living plant, and supplies it with nitrogen.

The effect of nitric acid is similar in kind, and perhaps equal in degree. Applied to the young grass or sprouting shoots of grain, it hastens and increases their growth, it occasions a larger produce of grain, and this grain, as when ammonia is employed, is richer in *gluten*, and more nutritious in its quality.† An equal breadth of the same field yields a heavier produce, and that produce, weight for weight, contains more when saltpetre or nitrate of soda have been applied in certain quantities to the young plants which grow upon it. It is reasonable to conclude, therefore, that the acid of the nitrates, in some form or other,

* When the beet-root arrives at maturity, the *sugar* begins to diminish, and saltpetre or other nitrates to be *formed*, probably at the expense of the ammonia which the juice previously contained.—Decroizelles, *Jour. de Phar.*, X., p. 42.

† The analogous effects of ammoniacal manures and of the nitrates on the relative quantities of *gluten* and starch in grain, are shown by the following experiments:

Hermbstaedt sowed equal quantities of the same wheat, on equal plots of the same ground, and manured them with equal weights of different manures. Then from 100 parts of each sample of grain produced, he obtained starch and gluten in the following proportions:

	Gluten.	Starch.	Produce.
Without manure	9·2	66·7	3 fold.
With vegetable manure (rotted potatoe haulm)	9·6	65·94	5 "
With cow dung	12·0	62·3	7 "
With pigeons' dung	12·2	63·2	9 "
With horse dung	13·7	61·64	10 "
With goats' dung	32·9	42·4	12 "
With sheep dung	32·9	42·8	12 "
With dried night-soil	33·14	41·44	14 "
With dried ox-blood	34·24	41·3	14 "
With dried human urine	35·1	39·3	12 "[1]

The manures employed by Hermbstaedt are *supposed*, during fermentation, to evolve more ammonia in the order in which they are here placed, beginning at the top of the list; while the amount and kind of the produce obtained by the use of each, afford the chief evidence in favour of the opinion that this ammonia actually enters into and yields nitrogen to the plant.

Mr. Hyett found in flour raised on two patches of the same land in Gloucestershire, the one dressed with nitrate of soda, the other undressed, the following proportions:

	Gluten.	Starch.
In the nitrated	23·25	49·5
In the unnitrated	19·	55·5

And Mr. Daubeny, [*Three Lectures on Agriculture*, p. 76,] in flour from wheat top-dressed with saltpetre, found—

In the nitrated	15 per cent. of gluten.
In the unnitrated	13 " "

These differences are not so striking as in the case of ammonia, but they are precisely *the same in kind*, and lead to the same general conclusion in regard to the nature of the influence of the nitrates on vegetation. Accurate and repeated experiments on the precise effects of the nitrates are still much to be desired.

[[1] Schübler. *Grundsätze der Agricultur Chemie*, II. p. 170.]

is capable of entering into the circulation of living plants—and of yielding to them, in whole or in part, the nitrogen they contain.

But here, again, as in the case of ammonia, we are at fault in regard to the quantity of nitrogen which plants in a state of nature actually derive from nitric acid or the nitrates. The compounds of this acid with potash, soda, lime, and magnesia (the nitrates of these substances), are all very soluble in water. The quantity of this fluid, therefore, which enters by the roots of plants, *could* easily convey into their circulation far more of these nitrates than would be alone sufficient to supply the whole of the nitrogen they require—for the formation of all their parts and products. But so it might of ammonia or its salts, as has already been shown. I shall hereafter lay before you certain considerations which may probably lead us to approximate conclusions in regard to the relative influence exercised by these two compounds on the general vegetation of the globe.

Conclusions.—Respecting the form in which nitrogen enters into the circulation of plants, we have therefore, I think, fairly arrived at these deductions:

1°. That the nitrogen of the atmosphere may, to a small extent, enter directly into the living vegetable either in the form of gas or in solution in water, but that supposing nitrogen to be in this way appropriated* by the plant, the quantity so taken up could form only a small quantity of that which vegetables actually contain.

2°. That ammonia is *capable* of entering into plants in very large quantity, and of yielding nitrogen to them, and that in European agriculture, which employs fermenting animal manure as an important means of promoting vegetable growth, it does appear to yield to cultivated plants a considerable portion of the nitrogen they contain.

3°. That nitric acid, in like manner, is *capable* of entering into and giving up its nitrogen to plants; and that where this acid is employed as an instrument of culture, the crops obtained owe part of their nitrogen to the quantity of this compound which has been applied to the growing plants. The same inference may fairly be drawn in regard to the effect of nitric acid—when, in the form of nitrates, it exists or is produced naturally in the soil.

4°. That other compound bodies, such as are contained in urine, or are produced during the decay of animal matter, may also enter into the circulation of plants, and yield nitrogen to promote their growth.

On the whole, however, there seem strong reasons for believing that plants are mainly dependent on ammonia and nitric acid for the nitrogen they contain; and that they obtain it most readily, and with least *labour*, so to speak, from these compounds,—though nature has kindly fitted them for deriving a stinted supply from other sources, when these substances are not present in sufficient abundance.

How far each of these compounds is employed by nature, as an instrument in promoting the general vegetation of the globe, will be considered in a subsequent lecture.

* Liebig and others say that plants are *incapable* of appropriating or assimilating the nitrogen which enters into their circulation in the simple state. We shall consider this question hereafter.

LECTURE V.

How does the food enter into the circulation of plants—Structure of the several parts of plants—Functions of the root—Course of the sap—Cause of its ascent—Functions of the stem—of the leaves—and of the bark—Circumstances by which the exercise of these functions is modified.

Having now taken a general view of the source from which plants derive the elementary substances of which their solid parts consist, and of the states of combination in which these elements enter into the vegetable circulation,—the next step in our inquiry is—*how* are these substances admitted into the interior of living plants—and under what conditions or regulations? We are thus led to study the structure and functions of the several parts of plants, and the circumstances by which the exercise of these functions is observed to be modified.

§ 1. *General structure of plants, and of their several parts.*

Plants consist essentially of three parts—the roots, the stem, and the leaves. The former spread themselves in various directions through the soil, as the latter do through the air, and the stem is dependent for its food and increase on the rapidity with which the roots shoot out and extend, and on the number and luxuriance of the leaves.

We shall obtain a clearer idea of the relative structure of these several parts by first directing our attention to that of the stem.

The stem consists apparently of four parts—the pith, the wood, the bark, and the medullary rays. The pith and the medullary rays, however, are similarly constituted, and are only prolongations of one and the same substance. The pith forms a solid cylinder of soft and spongy matter, which ascends through the central part of the stem, and varies in thickness with the species and with the age of the trunk or branch. The wood surrounds the pith in the form of a hollow cylinder, and is itself covered by another hollow cylinder of bark. In trees or branches of considerable age the wood consists of two parts, the oldest or *heart wood*, often of a brownish colour, and the newer external wood or *alburnum*, which is generally softer and less dense than the heart wood. The bark also is easily separated into two portions, the inner bark or *liber*, and the *epidermis* or outer covering of the tree. The pith and the bark are connected together by thin vertical columns or partitions, which intersect the wood and divide it into triangular segments. A cross section of the trunk or branch of a tree exhibits these thin columns extending in the form of rays, or like the spokes of a wheel, from the centre to the circumference. Though they form in reality thin and continuous vertical plates, yet from the appearance they present in the cross section of a piece of wood, they are distinguished by the name of medullary rays.

These several parts of the stem are composed of bundles of small tubes or hollow cylindrical vessels of various sizes, and of different kinds, the structure of which it is unnecessary for us to study. They

are all intended to contain liquid and gaseous substances, and to convey them in a vertical, and sometimes in a horizontal, direction. The tubes which compose the wood and bark are arranged vertically, as may readily be seen on examining a piece of wood even with the naked eye, and are intended to convey the sap upwards to the leaves and downwards to the roots. Those of which the pith and medullary plates consist are arranged horizontally, and appear to be intended to maintain a lateral intercourse between the pith and the bark—perhaps even to place the heart of the tree within the influence of the external air.

The root, though prior in its origin to the stem, may nevertheless for the purpose of illustration be considered as its downward and lateral prolongation into the earth—as the branches are its upward prolongation into the air.* When they leave the lower part of the trunk of the tree, they differ little in their internal structure from the stem itself. As they taper off, however, first the heart wood, then the pith, gradually disappear, till, towards their extremities, they consist only of a soft central woody part and its covering of soft bark. These are connected with, or are respectively prolongations of, the new wood and bark of the trunk and branches. At the extreme points of the roots the bark becomes white, soft, spongy, and full of pores and vessels. It is by these spongy extremities only, or chiefly, that liquid and gaseous substances are capable either of entering into, or of making their escape from, the interior of the root.

The branches and twigs are extensions of the trunk; and of the former, the leaves may be considered as a still further extension. The fibres of the leaf are minute ramifications of the woody matter of the twigs, are connected through them with the wood of the branches and stems, and from this wood receive the sap which they contain. The green part of the leaf may be considered as a special expansion of the bark, by which it is fitted to act upon the air, in the same way as the spongy mass into which the bark is changed at the extremity of the root, is fitted to act upon the water and other substances it meets with in the soil. For as the fibres of the leaf are connected with the wood of the stem, so the green part of the leaf is connected with its bark, and from this green part the sap first begins to descend towards the root.

§ 2. *The functions of the root.*

The position in which the roots of plants in their natural state are generally placed, has hitherto prevented their functions from being so accurately investigated as those of the leaves and of the stem. While, therefore, the main purposes they are intended to serve are universally

* The correctness of this comparison is proved by the fact that, in many trees, the branch if planted will become a root, and the root, if exposed to the air, will gradually be transformed into a branch. The banana in the forest, and the currant tree in our gardens, are familiar instances of trees spontaneously planting their branches, and causing them to perform the functions of roots. In like manner, "if the stem of a young plum or cherry-tree, or of a willow, be bent in the autumn so that one-half of the top can be laid in the earth and one-half of the root be at the same time taken carefully up—sheltered at first and afterwards gradually exposed to the cold—and if in the following year the remaining part of the top and root be treated in the same way, the branches of the top will become roots, and the ramifications of the roots will become branches, producing leaves, flowers, and fruit in due season.—[Loudon's *Encyclopædia of Agriculture.*] The tree is thus reversed in position, and the roots and branches being thus mutually convertible cannot be materially unlike in general structure.

known and understood, the precise way in which these ends are accomplished by the roots, and the powers with which they are invested, are still to a considerable degree matters of dispute.

I. It appears certain that they are possessed of the power of absorbing water in large quantity from the soil, and of transmitting it upwards to the stem. The amount of water thus absorbed depends greatly upon the nature of the soil and of the climate in which a plant grows, but much also upon the specific structure of its leaves and the extent of its foliage.

II. The analogy of the leaves and young twigs would lead us to suppose that, when in a proper state of moisture, the roots should also be capable of absorbing gaseous substances from the air which pervades the soil. Experiment, however, has not yet shown this to be the case.

We know, however, that they are capable of absorbing gases through the medium of water. For if the roots of a plant are placed in water containing carbonic acid in the state of solution, this gas is found gradually to disappear. It is extracted from the water by the roots. And if the water in which the roots are immersed be contained in a bottle only partially filled with the liquid, while the remainder is occupied by atmospheric air, the oxygen in this air will also slowly diminish. It will be absorbed by the roots through the medium of the water.*

Again, if in the place of the atmospheric air in this bottle, carbonic acid be substituted, the plant will droop and in a few days will die. The same will take place, if instead of common air or carbonic acid, nitrogen or hydrogen gases be introduced into the bottle. The plant will not live when its roots are exposed to the sole action of any of the three.

It is obvious, therefore, that the roots of plants absorb gaseous substances from the air which surrounds their roots, at least indirectly and through the medium of water. It appears also that from this air they have the power of *selecting* a certain portion of oxygen when this gas is present in it. Thirdly, that though they can absorb carbonic acid to a limited amount without injury to the plant, yet that a copious supply of this gas, unmixed with oxygen, is fatal to vegetable life. This deduction is confirmed by the fact that, in localities where carbonic acid ascends through fissures in the subjacent rocks and saturates the soil, the growth of grass is found to be very much retarded. And, lastly, since nitrogen is believed not to be in itself noxious to vegetable life, the death of the plant in water surrounded by this gas, is supposed to imply that the presence of oxygen is necessary about the roots of a growing and healthy plant, and that one of the special functions of the roots is constantly to absorb this oxygen.

This supposition is in accordance with the fact that, in the dark, the leaves of plants absorb oxygen from the atmosphere; for we have already seen reason to expect that; from their analogous structure, the roots and leaves in similar circumstances should perform also analogous functions. At the same time, if the roots do require the access and presence

* It will be recollected that water absorbs about 4 per cent. of its bulk of air from the atmosphere, of which about one-third is oxygen. If the roots extract this oxygen from the water, the latter will again drink in a fresh portion from the atmospheric air which floats above it.

of oxygen in the soil, it would further appear that those of some plants require it more than those of others; inasmuch as some genera, like the grasses, love an open and friable soil, into which the air is more completely excluded.—[Sprengel, *Chemie*, II., p. 337.]

III. We have in a former lecture (IV. p. 64) concluded from facts there stated, that solid substances, which are soluble in water, accompany this liquid when it enters into the circulation of the plant. This appears to be true both of organic and inorganic substances. Potash, soda, lime, and magnesia thus find their way into the interior of plants, as well as those substances of animal and vegetable origin to which the observations made in the fourth lecture were intended more especially to apply. Even *silica*,* considered to be almost insoluble in water, enters by the roots, and is found in some cases in considerable quantities in the stem. Some persons have hence been led to conclude that *solid* substances, undissolved, if in a minute state of division, may be drawn into the pores of the root and may then be carried by the sap upwards to the stem.

Considered as a mere question of vegetable mechanics, argued as such among physiologists, it is of little moment whether we adopt or reject this opinion. One physiologist may state that the pores by which the food enters into the roots are so minute as to baffle the powers of the best constructed microscope, and, therefore, that to no particles of solid matter can they by possibility give admission—while another may believe solid matter to be capable of a mechanical division so minute as to pass through the pores of the finest membrane. As to the mere fact itself, it matters not which is right, or which of the two we follow. The adoption of the latter opinion implies in itself merely that *foreign* substances, unnecessary, perhaps injurious to vegetable life, may be carried forward by the flowing juices until in some still part of the current, or in some narrower vessel, they are arrested and there permanently lodged in the solid substance of the plant.

By inference, however, the adoption of this opinion implies also, that the inorganic substances found in plants,—those which remain in the form of ash when the plant is burned,—are *accidental* only, not *essential* to its constitution. For since they may have been introduced in a mere state of minute mechanical division suspended in the sap, they ought to consist of such substances chiefly as the soil contains in the greatest abundance, and they ought to vary in kind and relative quantity with every variation in the soil. In a clay land the ash should consist chiefly of alumina,† in a sandy soil chiefly of silica. But if, as chemical inquiry appears to indicate, the nature of the ash is not *accidental*, but *essential*, and in some degree constant, even in very different soils, this latter inference is inadmissible;—and in reasoning backwards from this fact, we find ourselves constrained to reject the opinion that substances are capable of entering into the roots of plants in a solid state—and this without reference at all to the mechanical question, as to the relative size of the pores of the spongy roots or of the particles into which solid matter may be divided.

* Silica is the name given by chemists to the pure matter of flint or of rock crystal. Sand and sandstones consist almost entirely of silica.

† Alumina is the pure earth of clay.

IV. We are thus brought to the consideration of the alleged selecting power of the roots, which, if rightly attributed to them, must be considered as one of the most important functions of which they are possessed. It is a function, however, the existence of which is disputed by many eminent physiologists. But as the adoption or rejection of it will materially influence our reasonings, as well as our theoretical views, in regard to some of the most vital processes of vegetation,—it will be proper to weigh carefully the evidence on which this power is assigned to the roots of plants.

1°. The leaves, as we shall hereafter see, possess in a high degree the power of selecting from the atmosphere one or more gaseous substances, leaving the nitrogen, chiefly, unchanged in bulk. The absorption of carbonic acid and the diminution of the oxygen in the experiments above described, appear to be analogous effects, and would seem to imply in the roots the existence of a similar power.

2°. Dr. Daubeny found that pelargoniums, barley (*hordeum vulgare*), and the winged pea (*lotus tetragonolobus*), though made to grow in a soil containing much strontia,* appeared to absorb none of this earth, for none was found in the ash left by the stem and roots of the plant when burned. In like manner De Saussure observed that polygonum persicaria refused to absorb acetate of lime from the soil, though it freely took up common salt.—[Lindley's *Theory of Horticulture*, p. 19.]

3°. Plants of different species, growing in the same soil, leave, when burned, an ash which in every case contains either different substances, or the same substances in unlike proportions. Thus if a bean and a grain of wheat be grown side by side, the stem of the plant from the latter seed will be found to contain silica, from the former none.†

4°. But the same plant grown in soils unlike in character and composition, contains always—if they are present in the soil at all—very nearly the same kind‡ of earthy matters in nearly the same proportion. Thus the stalks of corn plants, of the grasses, of the bamboo, and of many others, always contain silica, in whatever soil they grow, or at least are capable of growing with any degree of luxuriance.

With the view of testing this point, Lampadius prepared five square patches of ground, manured them with equal quantities of a mixture of horse and cow dung, sowed them with equal measures of the same wheat, and on four of these patches strewed respectively five pounds of finely powdered quartz (siliceous sand), of chalk, of alumina, and of carbonate of magnesia, and left one undressed. The produce of seed from each, in the above order, weighed 24¼, 28¾, 26¼, 21½, and 20 ounces respectively. The grain, chaff, and straw, from each of the patches left nearly the same quantity of ash—the weights varying only from 3·7 to 4·08 per cent., and the roots and chaff being richest in inorganic matter. The relative proportions of silica, alumina, lime, and magnesia,

* Watered with a solution of nitrate of strontia. Strontia is an earthy substance resembling lime, which is found in certain rocks and mineral veins, but which has not hitherto been observed in the ashes of plants.

† It is not strictly correct that the bean will absorb *no* silica, but the quantity it will take up will be only one-thirteenth of that taken up by the wheat plant—the per centage of silica in the ash of bean straw being, according to Sprengel, only 0·22, while in wheat straw it is 2·87 per cent. Pea straw contains four times as much as that of the bean, or 0·996 per cent.

‡ For more precise information on this point, see the subsequent lectures, "*On the inorganic constituents of plants*," (Part II.)

were *the same in all.*—[Meyen *Jahresbericht*, 1839, p. 1.] Provided, therefore, the substances which plants prefer be present in the soil, the kind of inorganic matter they take up, or of ash they leave, is not *materially* affected by the presence of other substances, even in somewhat larger quantity.

These facts all point to the same conclusion, that the roots have the power of selecting from the soil in which they grow, those substances which are best fitted to promote the growth or to maintain the healthy condition of the plants they are destined to feed.

5°. It has been stated above that the roots of certain plants refuse to absorb nitrate of strontia and acetate of lime, though presented to them in a state of solution—the same is true of certain coloured solutions which have been found incapable of finding their way into the circulation of plants whose roots have been immersed in them. On the other hand, it is a matter of frequent observation that the roots absorb solutions containing substances which speedily cause the death of the plant. Arsenic, opium, salts of iron, of lead, and of copper, and many other substances, are capable of being absorbed in quantities which prove injurious to the living vegetable—and on this ground chiefly many physiologists refuse to acknowledge that the roots of plants are by nature endowed with any definite and constant power of selection at all. But this argument is of equal force against the possession of such a power by animals or even by man himself; since, with our more perfect discriminating powers, aided by our reason too, we every day swallow with our food what is more or less injurious, and occasionally even fatal, to human life.*

On the whole, therefore, it appears most reasonable to conclude that the roots are so constituted as (1°) to be able generally to select from the soil, *in preference*, those substances which are most suitable to the nature of the plant—(2°) where these are not to be met with, to admit certain others in their stead†—(3°) to refuse admission also to certain substances likely to injure the plant, though unable to discriminate and reject every thing hurtful or unbeneficial which may be presented to them in a state of solution.

The object of nature, indeed, seems to be to guard the plant against the more common and usual dangers only—not against such as rarely present themselves in the situations in which it is destined to grow, or against substances which are unlikely even to demand admission into its roots. How useless a waste of skill, if I may so speak, would it have been to endow the roots of each plant with the power of distinguishing and rejecting opium and arsenic and the thousand other poisonous substances which the physiologist can present to them, but which in a state of nature—on its natural soil and in its natural climate—the living vegetable is never destined to encounter!

* I may here remark that it is by no means an extraordinary power which these circumstances seem to show the roots of plants to possess. In the presence of oxygen, nitrogen, and carbonic acid, in equal quantities, water will prefer and will select the latter. From a mixture of lime and magnesia, acetic or sulphuric acid will select and separate the former. Is it unreasonable to suppose the roots of plants—the organs of a living being—to be endowed with powers of discrimination at least as great as those possessed by dead matter?

† This conclusion is not strictly contained in the premises above stated, but the facts from which it is drawn will be fully explained in treating of the inorganic constituents of plants. It is introduced here for the purpose of giving a complete view of what appears to be the true powers of discrimination possessed by the root.

V. Another function of the roots of plants, in regard to which physiologists are divided in opinion at the present day, is what is called their *excretory power*.

1°. When barley or other grain is caused to germinate in pure chalk, acetate of lime* is uniformly found to be mixed with it after the germination is somewhat advanced (Becquerel and Mateucci, *Ann. de Chem. et de Phys.*, lv., p. 310.) In this case the acetic acid must have been given off (excreted) by the young roots during the germination of the seed.

This fact may be considered as the foundation of the excretory theory as it is called. This theory, supported by the high authority of Decandolle, and illustrated by the apparently convincing experiments of Macaire, (*Ann. de Chim. et de Phys.*, lii., p. 225,) has more recently been met by counter-experiments of Braconnot, (lxxii. p. 27,) and is now in a great measure rejected by many eminent vegetable physiologists. It may indeed be considered as quite certain that the application of this theory by Decandolle and others to the explanation of the benefits arising from a rotation of crops, is not confirmed, or *proved* to be correct, by any experiments on the subject that have hitherto been published.†

According to Decandolle, plants, like animals, have the power of selecting from their food, as it passes through their vascular system, such portions as are likely to nourish them, and of rejecting, by their roots,

* Acetate of lime is a combination of acetic acid or vinegar with lime derived from the chalk.

† The discordant results of Macaire and Braconnot were as follow:

1°. Macaire observed that when plants of *Chondrilla Muralis* were grown in rain water they imparted to it something of the smell and taste of opium. Braconnot confirmed this, but attributed it to wounds in the roots which allowed the proper juice of the plant to escape. He says it is almost impossible to free the young roots from the soil in which they have grown, without injuring them and causing the sap to exude.

2°. *Euphorbia Peplus* (Petty Spurge) imparted to the water in which it grew a gummi-resinous substance of a very acrid taste. In the hands of Braconnot it yielded to the water scarcely any organic matter, and that only slightly bitterish.

3°. Braconnot washed the soil in which plants of *Euphorbia Bremi* and *Asclepias Incarnata* were growing in pots, and obtained a solution containing earthy and alkaline salts with only a trace of organic matter.

He also washed the soil in which the Poppy (*Papaver Somniferum*) had been grown ten years successively. The solution, besides inorganic earthy and alkaline salts, gave a considerable quantity of acetic acid (in the form of acetate of lime) and a trace of brown organic matter. He infers that these several plants do not excrete any organic matter in sufficient quantity to be injurious to themselves.

4°. Macaire observed that when separate portions of the roots of the same plant of *Mercurialis Annua* were immersed in separate vessels, the one containing pure water and the other a solution of acetate of lead,—the solution of lead was absorbed by the plant,—was to be traced in every part of it, and afterwards was partially transmitted to the pure water. Braconnot observed the same results, but he found the entrance of the lead into the second vessel to be owing to the ascent of the fluid up the outer surface of the one root and down the exterior of the other, and that, by preventing the possibility of this passage, no lead could be detected among the pure water.

The conclusions of Macaire, therefore, in favour of the rotation theory of Decandolle must be considered as at present inadmissible, and we shall hereafter see reason to coincide, at least to a certain extent, in the conclusion of Braconnot, "that if these excretions (of organic matter) really take place in the natural state of the plant, they are as yet so obscure and so little known as to justify the presumption that some other explanation must be given of the general system of rotation." Various illustrations have been given by different observers of this supposed excreting power of the roots. Among the most recent are those of *Nietner*, who ascribes the luxuriant rye crops obtained without manure after three years of clover, to the excretions of this plant in the soil, which, like those of the pea and bean to the wheat, he supposes to be nourishing food to the rye. He also states that the beet or the turnip after tobacco has an unpleasant taste, and is scarcely eatable, which he attributes to the excretions of the tobacco plant. Meyen ascribes the effect of the clover to the green manure supplied by its roots and stubble and that of the tobacco to the undecomposed organic substances contained in the sap and substance of the roots and stems of this plant, of which so large a quantity is left behind in the field.—(Meyen's *Jahresbericht*, 1839, p. 5.)—These objections of Meyen are not without their weight, but we shall hereafter see that they embody only half the truth.

when the sap descends, such as are unfit to contribute to their support, or would be hurtful to them if not rejected from their system. He further supposes that, after a time, the soil in which a certain kind of plant grows becomes so loaded with this rejected matter, that the same plant refuses any longer to flourish in it. And, thirdly, that though injurious to the plant from which it has been derived, this rejected matter may be wholesome food to plants of a different order, and hence the advantage to be derived from a rotation of crops.

There seems no good reason to doubt that the roots of plants do at times—it may be constantly—reject organic substances from their roots. The acetic acid given off during germination, and the same acid found by Braconnot in remarkable quantity in the soil in which the poppy (*papaver somniferum*) has grown—may be regarded as sufficient evidence of the fact—but the quantity of such organic matter hitherto detected among what may be safely viewed as the real excretions of plants, seems by far too small to account for the remarkable natural results attendant upon a rotation of crops.

The consideration of these results, as well as of the general theory of such a rotation, will form a distinct topic of consideration in a subsequent part of these lectures. I shall, therefore, only mention one or two facts which seem to me capable of explanation only on the supposition that the roots of plants are endowed with the power of rejecting, and that they do constantly reject, when the sap returns from the leaf, some of the substances which they had previously taken up from the soil.

1°. De Saussure made numerous experiments on the quantity of ash pe cent. left by the same plant at different periods of its growth. Among other results obtained by him, it appeared—

A. That the quantity of incombustible or inorganic matter in the different parts of the plant was different at different periods of the year. Thus the dry leaves of the horse chestnut, gathered in May, left 7·2 per cent., towards the end of July 8·4 per cent., and in the end of September 8·6 per cent. of ash; the dry leaves of the hazel in June left 6·2, and in September 7 per cent.; and those of the poplar (*populus nigra*) in May 6·6, and in September 9·3 per cent. of ash. These results are easily explained on the supposition that the roots continued to absorb and send up to the leaves during the whole summer the saline and earthy substances of which the ash consisted. But—

B. He observed also that the quantity of the inorganic substances in —or the ash left by—the *entire* plant, diminished as it approached to maturity. Thus the dry plants of the vetch, of the golden rod (*solidago vulgaris*), of the turnsol (*helianthus annuus*), and of wheat, left respectively of ash, at three different periods of their growth, [Davy's *Agricultural Chemistry*, Lecture III.]—

	Before flowering. *per cent.*	In flower *per cent.*	Seeds ripe. *per cent.*
Vetch	15	12·2	6·6
Golden rod . . .	9·2	5·7	5·0
Turnsol	14·7	13·7	9·3
Wheat	7·9	5·4	3·3

This diminution in the proportion of ash, might arise either from an increase in the absolute quantity of vegetable matter in the plants ac-

companying their increase in size—or from a portion of the saline and earthy matters they contained being again rejected by the roots. But if the former be the true explanation, the *relative proportions* of the several substances of which the ash itself consisted, in the several cases, should have been the same at the several periods when the experiments were made. But this was by no means the case. Thus, to refer only to the quantity of silica contained in the ash left by each of the above plants at the several stages of their growth, the ashes of the

	Before flowering. per cent.	In flower. per cent.	Seeds ripe. per cent.
Vetch contained . . .	1·5	1·5	1·75
Golden rod	1·5	1·5	3·5
Turnsol	1·5	1·5	3·75
Wheat	12·5	26·0	51·0

If, then, the proportion of silica in the ash increased in some cases four-fold, while the whole quantity of ash left by the plant decreased, it appears evident that some part of that which existed in the plant during the earlier periods of its growth must have been excreted or rejected by the roots, as it advanced towards maturity.

2°. This conclusion is confirmed and carried farther by another consideration. The quantity of ash left by the ripe wheat plant, in the above experiments of De Saussure, amounted to 3·3 per cent.;—of which ash, 51 per cent., or rather more than one-half, was silica. This silica, it is believed, could only have entered into the circulation of the plant in a state of solution in water, and could only be dissolved by the agency of potash or soda. But, according to Sprengel, the potash, soda, and silica, are to each other in the grain and straw of wheat, in the proportions of—

	Potash.	Soda.	Silica.
Grain	0·225	0·24	0·4
Straw	0·20	0·29	2·87

Or, supposing the grain to equal one-half the weight of the straw—their relative proportions in the whole plant will be nearly as 21 potash, 27 soda, 205 silica, or the weight of the silica is upwards of four times the weights of the potash and soda taken together.

Now silica requires nearly half its weight of potash to render it soluble in water,* or three-fifths of its weight of a mixture of nearly equal parts of potash and soda. The quantity of these *alkaline* substances *found* in the plant, therefore, is by no means sufficient to have dissolved and brought into its circulation the whole of the silica it contains. One of two things, therefore, must have taken place. Either a portion of the potash and soda present in the plant in the earlier stages of its growth must have escaped from its roots at a later stage,† leaving the silica behind it—or the same quantity of alkali must have circulated through the plant several times—bringing in its burden of silica, deposit-

* A soluble *glass* may be made by melting together in a crucible for six hours 10 parts of carbonate of potash, 15 of silica, and 1 of charcoal powder.

† De Saussure does not state the *exact* relative quantities of potash and soda at the several periods of the growth of wheat, though they appear to have gradually diminished. It seems, indeed, to be true of many plants, that the potash and soda they contain diminishes in quantity as their age increases. Thus the weight of potash in the juice of the ripe or sweet grape, is said to be less than in the unripe or sour grape—and the leaves of the potato have been found more rich in potash before than after blossoming (Liebig).

ing it in the vascular system of the plant, and again returning to the soil for a fresh supply. In either case the roots must have allowed it egress as well as ingress. But the fact, that the *proportion* of silica in the plant goes on increasing as it continues to grow, is in favour of the latter view—and renders it very probable that the same quantity of alkali returns again and again into the circulation, bringing with it supplies of silica and probably of other substances which the plant requires from the soil. And while this view appears to be the more probable, it also presents an interesting illustration of what may *probably* be the kind of function discharged by the potash and other inorganic substances found in the substance of plants—a question we shall hereafter have occasion to consider at some length.

The above considerations, therefore, to which I might add others of a similar kind, satisfy me that the roots of plants *do possess* the power of excreting various substances which are held in solution by the sap on its return from the stem—and which having performed their functions in the interior of the plant are no longer fitted, in their existing condition, to minister to its sustenance or growth. Nor is it likely that this excretory power is restricted solely to the emission of inorganic substances. Other soluble matters of organic origin are, no doubt, permitted to escape into the soil—though whether of such a kind as must necessarily be injurious to the plant from which they have been extruded, or to such a degree as *alone* to render a rotation of crops necessary, neither reasoning nor experiment has hitherto satisfactorily shown.

VI. The roots have the power of absorbing, and in some measure of selecting, food from the soil—can they also modify or alter it as it passes through them? A colourless sap is observed to ascend through the roots. From the very extremity up to the foot of the stem a cross section exhibits little trace of colouring matter, even when the soil contains animal and vegetable substances which are soluble, and which give dark coloured solutions, [such as the liquid manure of the fold-yard.] Does such matter never enter the root? If it does, it must be speedily changed or transformed into new compounds.

We have as yet too few experiments upon this subject to enable us to decide with any degree of certainty in regard to this function of the root.

It is probable, however, that as the sap passes through the plant, it is constantly, though gradually, undergoing a series of changes, from the time when it first enters the root till it again reaches it on its return from the leaf.

Can we conceive the existence of any powers in the root, or in the whole plant, of a still more refined kind? The germinating seed gives off acetic acid into the soil,—does this acetic acid dissolve lime from the soil and return with it again, as some suppose (Liebig), into the circulation of the plant?* Is acetic acid produced and excreted by the seed for this very refined purpose? We have concluded that in the wheat plant the potash and soda probably go and come several times during its growth, and the ripening of its seed. Is this a contrivance of nature to

* Braconnot found acetate of lime in very small quantities to be singularly hurtful to vegetation, and acetate of magnesia a little less so. He only mentions, however, some experiments upon *mercuriale annua*, [*Ann. de Chim. et de Phys.* lxxii. p. 36,] and as Saussure found that some plants actually refused to take it up at all, these acetates may not be equally injurious to all plants.

make up for the scarcity of alkaline substances in the soil—or would the same mode of operation be employed if potash and soda were present in greater abundance? Or where the alkalies are present in greater abundance, might not more work be done by them in the same time,—might not the plant be built up the faster and the larger, when there were more hands, so to speak, to do the work? Is the action of inorganic substances upon vegetation to be explained by the existence of a power resident in the roots or other parts of plants, by which such operations as this are directed or superintended? There are many mysteries connected with the nature and phenomena of vegetable life, which we have been unable as yet to induce nature to reveal to us.* But the morning light is already kindling on the tops of the mountains, and we may hope that the deepest vallies will not forever remain obscure.

§ 3. *The course of the sap.*

If the trunk of a tree be cut off above the roots, and the lower extremity be immediately plunged into a solution of madder or other colouring substances, the coloured liquid will ascend and will gradually tinge the wood. This ascent will continue till the colour can also be observed in the nerves of the leaf. If at this stage in the experiment the trunk be cut across at various heights, the wood alone will appear coloured, the bark remaining entirely untinged. But if the process be allowed still to continue when the coloured matter has reached the leaf, and after some further time the stem be cut across, the bark also will appear dyed, and the tinge will be perceptible further and further from the leaf the longer the experiment is carried on, till at length both bark and wood will be coloured to the very bottom of the stem.

Or if the root of a living plant, as in the experiment of Macaire detailed in a preceding note, be immersed in a metallic solution—such as a solution of acetate of lead,—which it is capable of absorbing without immediate injury, and different portions of the plant be examined after the lapse of different periods of time,—first the stem, afterwards the leaves, then the bark of the upper part of the stem, and lastly that of the lower part of the stem, will exhibit traces of lead.

These experiments show that the sap which enters by the roots ascends through the vessels of the wood, diffuses itself over the surface of leaves, and then descends by the bark to the extremities of the root.

But what becomes of the sap when it reaches the root? Is it delivered into the soil, or does it recommence the same course, and again, repeatedly perhaps, circulate through the stem, leaves, and bark? This question has been partly answered by what has been stated in the preceding section. When the sap reaches the extremity of the root, it appears to give off to the soil both solid and fluid substances of a kind and

* The roots of trees will travel to comparatively great distances, and in various directions, in search of water: the roots of sainfoin (*Esparsette*) will penetrate 10 or 12 feet through the calcareous rubbly subsoil, or down the fissures of limestone rocks on which they delight to grow. Is this the result of some *perceptive* power in the plant—or is it merely by *accident* that the roots display these tendencies?

Those who are in any degree acquainted with the speculations of the German physiologists of the greatest name—in regard to the *soul* and even the *immortality* of plants—will not accuse me of going very far in alluding to the possible existence of some such perceptive power in plants. Von Martius gets rid of objectors by speaking of them as "*scientific men to whom the power of comprehending the transcendental has been imparted in a lower degree.*" See Meyen's *Jahresbericht*, 1839, or *Silliman's Journal for January*, 1841, p. 170.

to an amount which probably differ with every species of plant. The remainder of the sap and of the substances it holds in solution must be diffused through the cellular spongy terminations of the roots, and, with the new supply of liquid imbibed from the soil, returned again to the stem with the ascending current.

But what causes the sap thus to ascend and descend? By what power is it first sucked up through the roots, and afterwards forced down again from the leaves? Several answers have been given to this question.

1°. When the end of a wide tube, either of metal or of glass, is plunged into water, the liquid will rise within the tube sensibly to the same level as that at which it stands in the vessel. But if a *capillary** tube be employed instead of one with a wide bore, the liquid will rise, and will permanently remain at a considerably higher level within than without the tube. The cause of this rise has been ascribed to an attraction which the sides of the tube have for the liquid, and which is sufficiently strong to raise it and to keep it up above the proper level of the water. The force itself is generally distinguished by the name of *capillary attraction.*

Now, the wood of a tree, as we have seen, is composed of a mass of fine tubes, and through these the sap has been said to rise by *capillary attraction.* But if the top of a vine be cut off when it is juicy and full of sap, the liquid will exude from the newly formed surface, and if the air be excluded, will flow for a length of time, and may be collected in a considerable quantity [Lindley's *Theory of Horticulture*, p. 47, note]. Such a flow of the sap is not to be accounted for by mere capillary attraction—the sides of tubes cannot draw up a fluid beyond their own extremities.

2°. To supply the defect of this hypothesis, De Saussure supposed that the fluid at first introduced by capillary attraction into the extremities of the root, was afterwards propelled upwards by the alternate contraction and expansion of the tubes of which the wood of the root and stem is composed. This alternate contraction and expansion he also supposed to be caused by a peculiar *irritating* property of the sap itself, which caused each successive part of the tube into which it found admission to contract for the purpose of expelling it. Mr. Knight also ascribed the ascent of the sap to a similar contraction of certain *other* parts of the stem. Being once raised, he supposed it to return again or descend by its own weight—but in drooping branches it is obvious that the sap must be actually driven or drawn upwards from the leaves on its return to the root. These explanations, therefore, are still unsatisfactory.

3°. If one end of an open glass tube be covered with a piece of moistened bladder or other fine animal membrane, tied tightly over it, and a strong solution of sugar in water be then poured into the open end of the tube, so as to cover the membrane to the depth of several inches, and if the closed end be then introduced to the depth of an inch below the surface of a vessel of pure water, the water will after a short time pass through the bladder inwards, and the column of liquid in the tube will increase in height. This ascent will continue, till in favourable circum-

* Glass tubes perforated by a very fine bore, like a human hair, are called *capillary* tubes. Such are those of which thermometers are usually made.

stances the fluid will reach the height of several feet, and will flow out or run over at the open end of the tube. At the same time the water in the vessel will become sweet, indicating that while so much liquid has passed through the membrane inwards, a quantity has also passed outwards, carrying sugar along with it.* To these opposite effects *Dutrochet*, who first drew attention to the fact, gave the names of *Endosmose*, denoting the inward progress, and *Exosmose*, the outward progress of the fluid. He supposed them to be due to the action of two opposite currents of electricity, and he likens the phenomena observed during the circulation of the sap in plants, to the appearances presented during the above experiment.

Without discussing the degree of probability which exists as to the influence of electricity in producing the phenomena of endosmose and exosmose, it must be admitted that the appearances themselves bear a strong resemblance to those presented in the absorption and excretion of fluids by the roots of plants—and point very distinctly to at least a kindred cause.

Thus, if the spongy termination of the root represent the thin porous membrane in the above experiment—the sap with which the tubes of the wood are filled, the artificial solution introduced into the experimental tube—and the water in the soil, the water or aqueous solution into which the closed extremity of the tube is introduced,—we have a series of conditions precisely similar to those in the experiment. Fluids ought consequently to enter from the soil into the roots, and thence to ascend into the stem, as in nature they appear to do.

This ascent, we have said, will continue till the fluid in the tubes of the wood (the sap) is reduced to a density as low as that of the liquid entering the roots from the soil. But in a growing tree, clothed with foliage, this will never happen. The leaves are continually exhaling aqueous vapour, as one of their constant functions, and sometimes in very large quantity. The sap, therefore, when it reaches the leaves, is concentrated or thickened, and rendered more dense by the separation of the water, so that when it descends to the root, and again begins its upward course, it will admit of large dilution before its density can be so far diminished as to approach that of the comparatively pure water which is absorbed from the soil. And this illustration of the ascent of the sap appears the more correct from the obvious purpose it points out —(in addition to others long recognised)—as served by the evaporation which is constantly taking place from the surface of the leaf.

Still the cause of the ascent of the sap is not the more clear that we can imitate it in some measure by an artificial experiment. But it will be conceded by the strictest reasoners on physical phenomena, that to have obtained the command, or even a partial control, over a natural

* Instead of sugar, common salt, gum, or other soluble substances may be dissolved in the water introduced at first into the tube, and the denser this solution the larger the quantity of water which will enter by the membrane, and the greater the height to which the column will rise. It ceases in all cases to rise only when the portions of liquid within and without the membrane attain nearly to the same density [*i. e.* contain nearly the same weight of solid matter in solution.] Instead of pure water the vessel into which the extremity of the tube is plunged may also contain a weak solution of some soluble substance—such as lime or soda —in which case, while the sugar, or salt, or gum, will pass outwards, in smaller quantity, the lime or soda will pass inwards, along with the currents of water in which they are severally dissolved.

power, is a considerable step towards a clear conception of the nature of that power itself. If the phenomena of endosmose can hereafter be clearly and indubitably traced to the agency of electricity we shall have advanced still another step, and shall be enabled to devise other means by which a more perfect imitation of nature may be effected, or a more complete control asserted over the phenomena of vegetable circulation.

§ 4. *Functions of the stem.*

The functions of the stem are probably as various as those of the root, though the circumstances under which they are performed necessarily involve these functions in considerable obscurity.

The pith which forms the central part of the stem consists, as I have already stated, of tubes disposed horizontally. When a coloured fluid is permitted to enter the lower part of the stem in the experiments above described, the pith remains untinctured in the centre of the coloured wood. It does not, therefore, serve for the conveyance of the sap. Nor does it seem to be vitally necessary to the health and growth of the plant, since Mr. Knight has shown that, from the interior of many trees, it may be removed without apparent injury, and in nature, as trees advance in age, it gradually diminishes in bulk, and in some species becomes apparently obliterated.

The vessels of the wood, which surrounds the pith, perform probably both a mechanical and a chemical function. They serve to convey upwards to the leaf the various substances which enter by the roots. This is their mechanical function. But during its progress upwards, the sap appears to undergo a series of changes. When it reaches the leaves it is no longer in the state in which it ascended from the root into the stem. The difficulty of extracting the sap from the wood, at different heights, has prevented very rigorous experiments from being made on its nature and contents at the several stages of its ascent. These it is obvious must vary with the species and age of the plant, and with the season of the year at which the experiment is made. But the general result to be drawn from such observations as have hitherto been made, is, that those substances which enter directly into the root, when mingled with such as have already passed through the circulation of the plant, undergo, during their ascent, a gradual preparation for that state in which they become fit to minister to the growth of the plant. This preparation is completed in a great measure in the leaf, though further changes still go on as the sap descends through the bark. This deduction is strengthened by the fact that gaseous substances of various kinds and in varying quantities exist in the interior of the wood of the growing plant. These gaseous subtances, according to Boucherie, are in some cases equal in bulk to one-twentieth part of the entire trunk of the tree in which they exist. They probably move upwards along with the sap, and are more or less completely discharged into the atmosphere through the pores of the leaves. That these gaseous substances not only differ in quantity, but in kind also, with the age and species of the tree, and with the season of the year, may, I think, be considered as almost amounting to a proof that they have not been inhaled directly by the roots, but are the result of chemical decompositions which

have taken place on the stem itself, as the sap mounted upwards towards the leaves.

We have seen that the roots exercise a kind of discriminating power in admitting to the circulation of the plant the various substances which are present in the soil. The vessels of the stem exhibit an analogous power of admitting or rejecting the solutions of different substances into which they may be immersed. Thus Boucherie states that, when the trunks of several trees of the same species are cut off above the roots, and the lower extremities immediately plunged into solutions of different substances, some of these solutions will quickly ascend into and penetrate the entire substance of the tree immersed in them, while others will not be admitted at all, or with extreme slowness only, by the vessels of the stems to which they are respectively presented. On the other hand, that which is rejected by one species will be readily admitted by another. Whether this partial stoppage of, or total refusal to admit, certain substances, be a mere *contractile* effort on the part of the vessels, or be the result of a chemical change by which their exclusion is effected or resisted, does not as yet clearly appear. That it does not depend upon the lightness and porosity of the wood, as might be supposed, is shown by the observation that the poplar is less easily penetrated in this way than the beech, and the willow than the pear tree, the maple, or the plane.

These various functions of the woody part of the stem are performed chiefly by the newer wood or *alburnum*, or, as it is often called, the sap wood of the tree. As the heart wood becomes older, the tubes of which it consists are either gradually stopped up by the deposition of solid substances which have entered by the roots, or by the formation of chemical compounds, which, like concretions in the bodies of animals, slowly increase in size till the vessels become entirely closed—or they are by degrees compressed laterally by the growth of wood around them, so as to become incapable of transmitting the ascending fluids. Perhaps the result is in most cases due in part to both these causes. This more or less perfect stoppage of the oldest vessels is one reason why the course of the sap is chiefly directed through the newer tubes.*

The functions of the bark, which forms the exterior portion of the stem, will be more advantageously described, after we shall have considered the purposes served by the leaves.

§ 5. *Functions of the leaves.*

The vessels of which the sap wood is composed extend upwards into the fibres of the leaf. Through these vessels the sap ascends, and from their extremities diffuses itself over the surface of the leaf. Here it undergoes important chemical changes, the extent, if not the exact nature, of which will appear from a short description of the functions which the leaves are known or are believed to discharge.

1°. When the roots of a living plant are immersed in water, it is a

* As the newest roots are prolongations of the newest wood, it may be supposed that the fact of these roots being the chief absorbents from the soil, is a sufficient reason why that which is absorbed by them should also pass up through the wood with which they are most closely connected. But that the pores of the heart wood are really incapable of transmitting fluids, is shown by plunging the newly cut stem of a tree into a coloured solution—the newer wood will be dyed, while more or less of the central portion will remain unchanged.

matter of familiar observation that the water gradually diminishes in bulk, and will at length entirely disappear, even when evaporation into the air is entirely prevented. The water which thus disappears is taken up by the roots of the plant, is carried up to the leaves, is there spread out over a large surface exposed to the sun and to the air, and in the form of vapour escapes in considerable proportion through the pores of the leaves and diffuses itself through the atmosphere.

The quantity of water which thus escapes from the surface of the leaves varies with the moisture of the soil, with the species of plant, with the temperature and moisture of the air, and with the season of the year. According to the experiments of Hales, it is also dependent on the presence of the sun, and is scarcely perceptible during the night. He found that a sun-flower, 3½ feet high, lost from its leaves during 12 hours of one day 30, and of another day 20 ounces of water, while during a warm night, without dew, it lost only three ounces, and in a dewy night underwent no diminution in weight.*

This loss of watery vapour by the leaf is ascribed to two different kinds of action. First, to a natural perspiration from the pores of the leaf, similar to the insensible perspiration which is continually proceeding from the skins of healthy animals; and second, to a mechanical evaporation like that which gradually takes place from the surface of moist bodies when exposed to hot or dry air. The relative amount of loss due to each of these two modes of action respectively, must differ very much in different species of plants, being dependent in a great measure on the special structure of the leaf. In all cases, however, the natural perspiration is believed very greatly to exceed the mere mechanical evaporation—though the results of Hales, and of other experimenters, show that both processes proceed with the greatest rapidity under the influence of a warm dry atmosphere, aided by the direct rays of the sun.

Among the several purposes served by this escape of watery vapour from the surface of the leaf, it is of importance for us to notice the direct

* When the escape of vapour from the leaves is more rapid than the supply of water from the roots, the leaves droop, dry, and wither. Such is sometimes the case with growing crops in very hot weather, and it always happens when a twig or flower is plucked and separated from the stem or root. When thus separated the leaves still continue to give off watery vapour into the air, and consequently the sap ascends from the twig or stalk to supply the place of the water thus exhaled.

But as the sap ascends it must leave the vessels empty of fluid, and air must rush in to fill the empty space. This will continue till nearly all the fluid has risen from the stem into the leaf, and the vessels of the wood are full of air. But if the stem of the twig or flower be placed in water this liquid will rise into it, air will be excluded, and the freshness and bloom of the leaves and flowers will be longer preserved. If the water into which they are introduced contain any substances in solution, these will rise along with the water, and will gradually make their way through all the vessels of the wood, till they can be detected in the leaves. By this means even large trees may in a short time be saturated with saline solutions, capable of preserving them from decay. It is only necessary to cut down or saw through the tree and insert its lower extremity into the prepared solution, when the action of the sun and air upon the leaves will cause it spontaneously to ascend. Thus *corrosive sublimate* (the subject of Kyan's Patent) may be injected with ease, or *pyrolignite of iron*, (iron dissolved in wood vinegar,) which Boucherie recommends as equally efficient and much more economical, [*Ann. de Chim. et de Phys.* lxxiv. p. 113.] The process is finished when the liquid is found to have risen to the leaf. Coloured solutions may in the same way be injected and the wood tinged to any required shade. One of the chief benefits attendant upon the cutting of wood in the winter, appears to be that the absence of leaves prevents the exhaustion of the sap and the ascent of air into the vessels of the wood—the oxygen of this air tending to induce decay. But the sap may be retained, and the air excluded almost as effectually, at any other season of the year, by stripping the tree of its leaves and branches a few days before it is cut down.

chemical influence it exercises over the growth of the plant. As the water disappears from the leaf, the roots must absorb from the soil at least an equal supply. This water brings with it the soluble substances, organic and inorganic, which the soil contains, and thus in proportion to the activity with which the leaves lose their watery vapour, will be the quantity of those substances which enter from the soil into the general circulation of the plant. This enables us to understand how substances, very sparingly soluble in water, should yet be found in the interior of plants, and in very considerable quantity, at almost every stage of their growth.

2°. Besides watery vapour, however, the leaves of nearly all plants exhale at the same time other volatile compounds in greater or less abundance. In the petals of flowers, we are familiar with such exhalations—often of an agreeable and odoriferous character. In the case of plants and trees also which emit a sensible odour, we readily recognise the fact of volatile substances being given off by the leaves. But even when the sense of smell gives us no indication of their emission from a single leaf or a single plant, the introduction of a number of such inodorous plants into the confined atmosphere of a small room after a time satisfies us that even they part with some volatile matter from their leaves, which makes itself perceptible to our imperfect organs only when in a concentrated state. The probability therefore is, that the leaves of all plants emit, along with the watery vapour which they evolve, certain other volatile substances also, though often in quantities so minute as to escape detection by our unaided senses. By the emission of these substances the plant probably relieves itself of what would prove injurious if retained, though of the chemical nature and composition of these exhalations little or nothing has yet been ascertained.

3°. If the branch of a living plant be so bent that some of its leaves can be introduced beneath the edge of an inverted tumbler full of water, and if the leaves be then exposed to the rays of the sun, bubbles of gas will be seen to form on the leaf, and gradually to rise through the water and collect in the bottom of the tumbler. If this gas be examined it will be found to be pure oxygen.

If the water contain carbonic acid gas, or if during the experiment a little carbonic acid be introduced, this gas will be found gradually to disappear, while the oxygen will continue to accumulate.

Or if the experiment be made by introducing a living plant into a large bell-glass full of common atmospheric air, allowing it to grow there for 12 hours in the sunshine, and then examining or analysing the air contained in the glass, the result will be of a precisely similar kind. The per centage of oxygen in the air will have increased.* And if the experiment be varied by the introduction of a small quantity of carbonic acid gas into the jar, this gas will be found as before to diminish in quantity, while the oxygen increases. The conclusion drawn from these experiments, therefore, is, that *the leaves of plants, when exposed to the rays of the sun, absorb carbonic acid from the air and give off pure oxygen gas.*

It has been already stated that the proportion of carbonic acid present

* It will be remembered that atmospheric air contains about 21 per cent. of oxygen gas.

in the atmosphere is exceedingly small, [about 1-2500th of this bulk—see Lecture II., p. 30;] but if for the purpose of experiment we increase this proportion in a gallon of air to five or ten per cent., introduce a living plant into it, and expose it to the sunshine, the carbonic acid will gradually disappear as before, while the oxygen will increase. And if we analyse the air and estimate the exact bulk of each of these gases present in it at the close of our experiment, we shall find that the oxygen has increased generally by as much as the carbonic acid has diminished. That is to say, if five cubic inches of the latter have disappeared, five cubic inches will have been added to the bulk of the oxygen. The above general conclusion, therefore, is rendered more precise by this experiment, which appears to show *that under the influence of the sun's rays the leaves of plants absorb carbonic acid from the air, and at the same time give off* AN EQUAL BULK *of oxygen gas.*

And as carbonic acid (CO_2) contains its own bulk of oxygen gas* combined with a certain known weight of carbon, it is further inferred that the oxygen given off by the leaves is the same which has been previously absorbed in the form of carbonic acid, and therefore it is usually stated as a function of the leaves—that *in the sunshine they absorb carbonic acid from the air,* DECOMPOSE *it in the interior of the leaf, retain its carbon, and again reject or emit the oxygen it contained.*

This conclusion presents a very simple view of the relations of oxygen and carbonic acid respectively to the living leaf in the presence of the sun, and it appears to be fairly deduced from the facts above stated. It has occasionally been observed, however, that the bulk of oxygen given off by the leaf has not been precisely equal to that of the carbonic acid absorbed, [see Persoz, *Chimie Moleculaire*, p. 54,] and hence it is also fairly concluded that a portion of the oxygen of the carbonic acid which enters the leaf is retained, and made available in the production of the various substances which are formed in the vascular system of different plants. On the other hand it is stated by Sprengel, that if compounds containing much oxygen be presented to the roots of plants, and thus introduced into the circulation, they are also decomposed, and the oxygen they contain in part or in whole given off by the leaves, so that, under certain circumstances, the bulk of the oxygen which escapes is actually greater than that of the carbonic acid which is absorbed by the leaves. Such is the case, for example, when the roots are moistened with water containing carbonic, sulphuric, or nitric acids.—[Sprengel *Chemie*, II., p. 344.]

It is of importance to note these deviations from apparent simplicity in the relative bulks of the two gases which are respectively given off and absorbed by all living vegetables. There are numerous cases of the formation of substances in the interior of plants which theory would fail to account for with any degree of ease, were these apparent anomalies to be neglected. This will more distinctly appear when in a subsequent lecture we shall inquire *how* or by what chemical changes the substances which plants contain, or of which they consist, are produced from the food which they draw from the air and from the soil.

* This the reader will recollect is proved by burning charcoal in a bottle of oxygen gas till combustion ceases, when nearly the whole of the oxygen is converted into carbonic acid, but without change of bulk.—See Lecture III., p. 45.

The most general and probable expression, therefore, for the function of the leaf, now under consideration, appears to be that in the sunshine the leaves absorb from the air carbonic acid, and at the same time evolve oxygen gas, the bulk of the latter gas given off being nearly equal to that of the former which is taken in—the relative bulks of the two gases varying more or less with the species of plant, as well as with the circumstances under which it is caused or is fitted to grow.*

4°. Such is the relation of the leaf to the oxygen and carbonic acid of the atmosphere in the presence of the sun. During the night their action is reversed, they *emit carbonic acid and absorb oxygen.* This is proved by experiments similar to those above described. For if the plant which has remained under the bell-glass for 12 hours in the sunshine—during which time the oxygen has sensibly increased, and the carbonic acid diminished in bulk—be allowed to remain in the same air through the following night, the oxygen will be found to have decreased, while the carbonic acid will be present in larger quantity than in the evening of the previous day.

The carbonic acid thus given off during the night is supposed to be partly derived from the soil through the roots, and partly from the substance of the plant itself. The oxygen absorbed either combines with the carbon of the plant to form a portion of the carbonic acid which is at the same time given off or is employed in producing some of the other *oxidixed* [containing oxygen in considerable quantity] compounds that exist in the sap.

As a general rule, the quantity of carbonic acid given off during the night is far from being equal to that which is absorbed during the day. Still it is obvious that a plant loses carbon precisely in proportion to the amount of this gas given off. Hence, when the days are longest, the plant will lose the least, and where the sun is brightest it will gain the fastest; since other things being equal, the decomposition of carbonic acid proceeds most rapidly where the sky is the clearest, and the rays of the sun most powerful. Hence we see why in Northern regions, where spring, summer, and autumn are all comprised in one long day —vegetation should proceed with such rapidity. The decomposition of the carbonic acid goes on without intermission, the leaves have no night of rest, but nature has kindly provided that, where the season of warmth is so fleeting, there should be no cessation to the necessary growth of food for man and beast.

This comparison of the functions performed by the leaf, during the day and night respectively, explains the chemical nature of the *blanching* of vegetables practised by the gardener, as well as the cause of the pale colour of plants that grow naturally in the absence of light.

When exposed to the sun, the leaves of these sickly vegetables evolve oxygen, and gradually become green and healthy. Woody matter is formed, and the stems become strong and fibrous.

The light of the sun, in the existing economy of nature, is indeed equally necessary to the health of plants and of animals. The former

* As the oxygen given off by the leaves is always the result of a chemical decomposition, by which the carbonic acid or other compound is deprived of a portion, at least, of its oxygen or de-oxidized, this function of the leaves in the presence of the sun is often spoken of as their *de-oxidizing* power.

become pale and sickly, and refuse to perform their most important chemical functions when excluded from the light. The bloom disappears from the human cheek, the body wastes away, and the spirit sinks, when the unhappy prisoner is debarred from the sight of the blessed sun. In *his* system, too, the presence of light is necessary to the performance of those *chemical* functions on which the healthy condition of the vital fluids depends.

The processes by which oxygen and carbonic acid are respectively evolved in plants have been likened by physiologists to the respiration and digestion of animals. It is supposed that when plants respire they give off carbonic acid as animals do, and that when they digest they evolve oxygen. Respiration also, it is said, proceeds at all times, digestion only in the light of the sun. Though these views are confessedly conjectural, they are founded upon striking analogies, and may reasonably be entertained as matters of opinion.

6°. Other species of decomposition also, besides that of *de-oxidization*, go on in the leaf, or are there made manifest. Thus when plants grow in a soil containing much common salt (chloride of sodium) or other chlorides, they have been observed by Sprengel and Meyen to evolve chloride* gas from their leaves. This takes place, however, more during the night than during the day. Some plants also give off ammonia, (Lecture IV., p. 70,) while others (cruciferæ), according to Dr. Daubeny, [in his *Three Lectures on Agriculture*, p. 59,] emit from their leaves pure nitrogen gas.

The evolution of chlorine implies the previous decomposition of the chlorides, which have been absorbed from the soil; while that of nitrogen may be due to the decomposition of ammonia, of nitric acid, or of some other compound containing nitrogen, which has entered into the circulation by the roots. The exact mode and nature of the decomposition of these substances, and the purposes served by them in the vegetable economy, will come under our consideration in a subsequent lecture.

The leaf has been described (p. 76) as an expansion of the bark. It consists internally of two layers of veins or vascular fibres laid one over the other, the upper connected with the wood—the lower with the inner bark. It is covered on both sides by a thin membrane (epidermis), the expansion of the outer bark. This thin membane is studded with numerous small pores or mouths (stomata), which vary in size and in number with the nature of the plant, and with the circumstances in which it is intended to grow. It is from the pores in the upper part of the leaf that substances are supposed to be exhaled, while every thing that is inhaled enters by those which are observed in the under side of the leaf.† This opinion, however, is not universally received, it being admitted by some that the power both of absorbing and of emitting may be possessed by the under surface of the leaf.

7°. We have seen that the chief supply of the fluids which constitute

* Chlorine is a gas of a greenish yellow colour, having an unpleasant taste and a suffocating odour. When it combines with other substances it forms *chlorides*. It exists in, and imparts its smell to, *chloride of lime*, which is employed for disinfecting purposes, and it forms upwards of half the weight of common salt.

† This is illustrated by the action of a cabbage leaf on a wound. If the upper side be applied, the sore is protected and quickly heals, while the under side *draws* it and produces a constant discharge.

the sap of plants, is derived from the soil. The under side of the leaves of plants is also supposed by some to be capable of absorbing moisture from the air, either in the form of watery vapour, or when it falls upon the leaves in the state of dew. Like the roots also they may absorb with the dew any substances the latter happens to hold in solution. And thus plants may, in some degree, be nourished by the volatile organic substances which ascend from the earth during the heat of the day, and which are again in a great measure precipitated with the evening dew.

Whether the leaves ever absorb nitrogen gas from the air has not as yet been determined with sufficient accuracy. If they do, it must in general be in very small quantity only, since it has hitherto escaped detection. In like manner it is doubtful how far they regularly absorb any other substances which the air is supposed to contain. Thus it is known that nitric acid exists in the air in very minute quantity. Some chemists also believe that ammonia is extensively diffused through the atmosphere in an exceedingly diluted state. Do the leaves of plants absorb these substances? Is the absorption of them one of the constant and necessary functions of the leaves? The reply to these questions must be very uncertain, and any principle which professes to be based upon such a reply must be regarded only as a matter of opinion.

8°. The petals of flower-leaves perform a somewhat different function from those of the ordinary leaves of a plant. They absorb oxygen at all times—though more by day than by night—and they constantly emit carbonic acid. The bulk of the latter gas evolved, however, is less than that of the oxygen taken in. The absorption of oxygen gas, and the constant production of carbonic acid, is, in some flowers, so great as to cause a perceptible increase of temperature—and to this slow combustion, so to speak, the proper heat observed in the flowers of many plants has been attributed.

According to some authors, the flower-leaves also emit pure nitrogen gas.—[Sprengel, *Chemie*, II., p. 347.] This fact has not yet been determined by a sufficient number of accurate experiments; it is in accordance, however, with the results of Boussingault, that, when a plant flowers and approaches to maturity, the nitrogen it contains becomes less. If confirmed, this evolution of nitrogen would throw an interesting light on the most advantageous employment of green crops, both for the purposes of manure and for the feeding of cattle.

9°. When the leaves of a plant begin to decay, either naturally as in autumn, or from artificial or accidental causes, they no longer absorb and decompose carbonic acid, even under the influence of the sun's rays. On the contrary, they absorb oxygen, like the petals of the flower, new compounds are formed within their substance—their green colour disappears—they become yellow—they wither, die, and drop from the tree—their final function, as the organs of a living being, is discharged. They then undergo new changes, are subjected to a new series of influences, and are made to serve new purposes in the economy of nature. These we shall hereafter find to be no less interesting and important in reference to a further end, than are the functions of the living leaf to the growth and nourishment of the plant.—[See subsequent lecture, "*On the law of the decay of organic substances.*"]

§ 6. *Functions of the bark.*

The inner bark being connected with the under layer of vessels in the leaf, receives from them the sap after it has been changed by the action of the air and light, and transmits it downwards to the root.

The outer bark, especially in young twigs and in the stalks of the grasses, so closely resembles the leaves in its appearance, that we can have no difficulty in admitting that it must, not unfrequently, perform similar functions. In the Cactus, the Stapelia, and other plants which produce no true leaves, this outer bark seems to perform all the functions which in other vegetable tribes are specially assigned to the abundant foliage. During its descent through the inner bark, therefore, the sap must in very many cases undergo chemical changes, more or less analogous to those which usually take place in the leaf.

It is by means of the inner bark that the stems of trees, such as our forest and fruit trees, are enlarged by the deposition of annual layers of new wood. The woody fibre is formed or prepared in the leaf, and as the sap descends it is deposited beneath the inner surface of the inner bark. It thus happens that, as the sap descends, it is gradually deprived of the substances it held in solution when it left the leaf, and in consequence it becomes difficult to say how much of the change, which the sap is found to have undergone when it reaches the root, is due to chemical transformations produced during its descent, and how much to the deposition of the woody fibre and other matters it has parted with by the way.

Among other evidences of such changes really taking place during the descent of the sap, I may mention an observation of Meyen [*Jahresbericht*, 1839, p. 27], made in the course of his experiments on the reproduction of the bark of trees. In these experiments he enclosed the naked wood in strong glass tubes, and in three cases out of eight the tubes were burst and shattered in pieces. This could only have arisen from the disengagement of gaseous substances, the result of decomposition. While, therefore, such gases as enter by the roots or are evolved in the vessels of the wood during the ascent of the sap, escape by the leaf along with those which are disengaged in the leaf itself, it is probable that those which are produced as the result of changes in the bark, descend with the downward sap, and are discharged by the root.*

In the bark of the root it is probable that still further changes take place—and of a kind which can only be effected during the absence of light. This is rendered probable by the fact that the bark of the root frequently contains substances which are not to be met with in any other part of the plant. Thus from the bark of the fresh root of the apple tree a substance named *phloridzine*, possessed of considerable medical virtues, may be readily extracted, though it does not exist in the bark either of the stem or of the branches.

In fine, as the food which is introduced into the stomachs of animals, undergoes continual and successive chemical changes during its progress through the entire alimentary canal—so, numerous phenomena indicate that the sap of plants is also subjected to unceasing transforma-

* Sprengel says that the stems and twigs, and the stalks of the grasses, all absorb oxygen and give off carbonic acid.—*Chemie*, II., p. 341.

tions,—in the root and in the stem as well as in the leaves,—at one time in the dark, at another under the influence of the sun's rays,—exposed when in the leaf to the full action of the air,—and when in the root almost wholly secluded from its presence;—the new compounds produced in every instance being suited either to the nature of the plant or the wants and functions of that part of it in which each transformation takes place.

To some of these transformations it will be necessary to advert more particularly, when we come to consider the special changes by which those substances of which plants chiefly consist, are formed out of these compounds on which they chiefly live.

§ 7. *Circumstances by which the functions of the various parts of plants are modified.*

Plants grow more or less luxuriantly, and their several parts are more or less largely developed, in obedience to numerous and varied circumstances.

I. In regard to the special functions of the root, we have already seen that the access of atmospheric air is in some cases indispensable, while in others, by shooting vertically downwards, the roots appear to shun the approach of either air or light. It is obvious also that a certain degree of moisture in the soil, and a certain temperature, are necessary to the most healthy discharge of the functions of the root. In hot weather the plant droops, because the roots do not absorb water from the soil with sufficient rapidity. And though it is probable that, at every temperature above that of absolute freezing, the food contained in the soil is absorbed and transmitted more or less slowly to the stem, yet it is well known that a genial warmth in the soil stimulates the roots to increased activity. The practice of gardeners in applying *bottom* heat in the artificial climate of the green-house and conservatory is founded on this well-known principle.

But the nature of the soil in which plants grow has also much influence on the way in which the functions of the root are discharged. As a general fact this also is well known, though the special qualities of the soil on which the greater or less activity of vegetation depends, are far from being generally understood. If the soil contain a sensible quantity of any substance which is noxious to plants, it is plain that their roots will be to a certain degree enfeebled, and their functions in consequence only imperfectly discharged. Or if the soil be deficient either in organic food, or in one or other of those inorganic substances which the plants necessarily require for the production of their several parts, the roots cannot perform their office with any degree of efficiency. Where the necessary materials are wanting the builder must cease to work. So in a soil which contains no silica, the grain of wheat may germinate, but he stalk cannot be produced in a natural or healthy state, since silica is indispensable to its healthy construction.

II. The ascent of the sap is modified chiefly by the season of the year, by the heat of the day, and by the genus and age of the plant or tree.

There seems reason to believe that the plant never sleeps, that even during the winter the circulation slowly proceeds, though the first

genial sunshine of the early spring stimulates it to increased activity. The general increased temperature of the air does not produce this acceleration in so remarkable a manner as the direct rays of the sun. The sap will flow and circulate on the side of a tree on which the sunshine falls, while it remains sensibly stagnant on the other. This is shown by the cutting down similar trees at more and more advanced periods of the spring, and immersing their lower extremities in coloured solutions. The wood and bark on one side of the tree will be coloured, while, on the other, both will remain unstained. If a similar difference in the comparative rapidity of the circulation on opposite sides of a trunk or branch be supposed to prevail more or less throughout the year, we can readily account for the annual layers of wood being often thicker on the one half of the circumference of the stem than on the other.

The sap is generally supposed to flow most rapidly during the spring, but if trees be cut down at different seasons, and immersed as above described, the coloured solution, according to Boucherie, reaches the leaves most rapidly in the autumn.*

The heat of the day, other circumstances being the same, materially affects, for the time, the rapidity of the circulation. The more rapidly watery and other vapours are exhaled from the leaves, the more quickly must the sap flow upwards to supply the waste. If on two successive days the loss by the leaves be, as in the experiment of Hales, above described, (p. 90,) as 2 to 3, the ascent of the sap must be accelerated or retarded in a similar proportion. Hence, every sensible variation in the temperature and moisture of the air, must also, to a certain extent, modify the flow of the sap; must cause a greater or less transport of that food which the earth supplies, to be carried to every part of the plant, and must thus sensibly affect the luxuriance and growth of the whole.

But the persistance of the leaves is a generic character, which has considerable influence upon the circulation in the *evergreens*. In the pine and the holly, from which the leaves do not fall in the autumn, the sap ascends and descends during all the colder months,—at a slower rate, it is true, than in the hot days of summer, yet much more sensibly than in the oak and ash, which spread their naked arms through the wintery air. This is illustrated by the experiments of Boucherie, who has observed that in December and January the entire wood of resinous trees may be readily and thoroughly penetrated by the spontaneous ascent of saline and other solutions, into which their stems may be immersed.

III. From what has just been stated, it will appear that the mechanical functions of the stem are subject to precisely the same influences as the ascent of the sap. As the tree advances in age, the vessels of the interior will become more or less obliterated, and the general course of the sap will be gradually transferred to annual layers, more and more

* Boucherie makes a distinction, not hitherto insisted upon by physiologists, between the circulation on the surface of the tree by which the buds and young twigs are supported, and the interior circulation, which is not perfect until a latter period of the year. Hence in the spring, though the sap is flowing rapidly through the bark and the newest wood, coloured solutions will not penetrate the interior of the tree with any degree of rapidity. In autumn, on the other hand—when the fear of approaching winter has already descended upon the bark—the time of most active circulation has only arrived for the interior layers of the older wood. It is this season consequently that he finds most favourable for impregnating the trunks of trees with those solutions which are likely to preserve them from decay,—*Ann. de Chim. et de Phys.*, lxxiv., p. 135.

removed from the centre. It is this transference of the vital circulation to newer and more perfect vessels that enables the tree to grow and blossom and bear fruit through so long a life. In animals the vessels are gradually worn out by incessant action. None of them, through old age, are permitted to retire from the service of the body—and the whole system must stop when one of them is incapacitated for the further performance of its appointed duties.

In regard to the *chemical* functions of the stem, it is obvious that they are not assigned to the mere woody matter of the vessels and cells. They take place in these vessels, but the nature and extent of the chemical changes themselves must be dependent upon the quantity and kinds of matter which ascend or descend in the sap. The entire chemical functions of the plant, therefore, must be dependent upon and must be modified by the nature of the substances which the soil and the air respectively present to the roots and to the leaves.

IV. In describing the functions of the leaf, I have already had occasion to advert to the greater number of the circumstances by which the discharge of those functions is most materially affected. We have seen that the purposes served by the leaf are entirely different according as the sun is above or below the horizon; that the temperature and moisture of the air may indeed materially influence the rapidity with which its functions are discharged—but that the light of the sun actually determines their nature. Thus the leaf becomes green and oxygen is given off in the presence of the sun, while in his absence carbonic acid is disengaged, and the whole plant is blanched.

How necessary light is to the health of plants may be inferred from the eagerness with which they appear to long for it. How intensely does the sun-flower watch the daily course of the sun,—how do the countless blossoms nightly droop when he retires,—and the blanched plant strive to reach an open chink through which his light may reach it!*

That the *warmth* of the sun has comparatively little to do with this specific action of his rays on the chemical functions of the leaf, is illustrated by some interesting experiments of Mr. Hunt, on the effect of rays of light of different colours on the growing plant. He sowed cress seed, and exposed different portions of the soil in which the seeds were germinating, to the action of the red, yellow, green, and blue rays, which were transmitted by equal thicknesses of solutions of these several colours. "After ten days, there was under the blue fluid, a crop of cress of as bright a green as any which grew in full light and far more abundant. The crop was scanty under the green fluid, and of a pale yellow, unhealthy colour. Under the yellow solution, only two or three plants appeared, but less pale than those under the green,—while beneath the red, a few more plants came up than under the yellow, though they also were of an unhealthy colour. The red and blue bottles being now mutually transferred, the crop formerly beneath the blue in a few

* A potato has been observed to grow up in quest of light from the bottom of a well twelve feet deep—and in a dark cellar a shoot of 20 feet in length has been met with, the extremity of which had reached and rested at an open window. In the leaves of blanched vegetables peculiar chemical compounds are formed. Thus in the stalk of the potato a poisonous substance called *solanin* is produced, which disappears again when the stalk is exposed to the light and becomes green.

days appeared blighted, while on the patch previously exposed to the red, some additional plants sprung up."*

Besides the rays of heat and of light, the sun-beam contains what have been called chemical rays, not distinguishable by our senses, but capable of being recognized by the chemical effects they produce. These rays appear to differ in kind, as the rays of different coloured light do. It is to the action of these chemical rays on the leaf, and especially to those which are associated with the blue light in the solar beam, that the chemical influence of the sun on the functions of the leaf is principally to be ascribed.

It cannot be doubted that the warmth and moisture of a tropical climate act as powerful stimulants—assistants it may be—to the leaf, in the absorption of carbonic acid from the air, and in that rapid appropriation (assimilation) of its carbon by which the growth of the plant is hastened and promoted. But the bright sun, and especially the chemical influence of his beams, must be regarded as the main agent in the wonderful development of a tropical vegetation. Under this influence the growth by the leaves at the expense of the air must be materially increased, and the plant be rendered less dependent upon the root and the soil for the food on which it lives.†

V. The rapidity with which a plant grows has an important influence upon the share which the *bark* is permitted to take in the general nourishment of the whole. The green shoot performs in some degree the functions of the leaf. In vascular plants, therefore, which in a congenial climate may almost be seen to grow, the entire rind of a tall tree may more or less effectually absorb carbonic acid from the atmosphere, during the presence of the sun. The broad leaves of the palm tree, when fully developed, render the plant in a great degree independent of the soil for organic food—and the large amount of absorbing surface in the long green tender stalks of the grasses, and of their tropical analogues, must materially contribute to the same end. Hence the proportion of organic matter derived from the air, in any crop we reap, must always be the greater the more rapid its general vegetation has been.

It is a fact familiarly known to all of you, that, besides those circumstances by which we can perceive the special functions of any one organ to be modified, there are many by which the entire economy of the plant is materially and simultaneously affected. On this fact the practice of agriculture is founded, and the various processes adopted by the practical farmer are only so many modes by which he hopes to influ-

* *London and Edinburgh Journal of Science, February*, 1840.

Might not our cheap blue glass be used with advantage in glazing hot-houses, conservatories, &c.?

† The effect of continued sunshine may be often seen in our corn-fields in May, when, under the influence of propitious weather, the young plants are shooting rapidly up. When such a field is bounded by a lofty hedge running nearly north and south, the ridges nearest the hedge on either side will be in the shade for nearly one-half of the day, and will invariably appear of a paler green and less healthy colour. If the hedge be studded with occasional large trees, the spots on which the shadows of those trees rest will be indicated by distinct pale green patches stretching further into the field than the first, and sometimes even than the second ridges.

ence and promote the growth of the whole plant, and the discharge of the functions of all its parts.

Though manures in the soil act immediately through the roots, they stimulate the growth of the entire plant; and though the application of a top-dressing may be supposed first to affect the leaf, yet the beneficial result of the experiment depends upon the influence which the dressing may exercise on every part of the vegetable tissue.

In connection with this part of the subject, therefore, I shall only further advert to a very remarkable fact mentioned by Sprengel, which seems, if correct, to be susceptible of important practical applications. He states that it has very frequently been observed in Holstein, that if, on an extent of level ground sown with corn, some fields be marled, and others left unmarled, the corn on the latter portions will grow *less luxuriantly* and will *yield a poorer crop than if the whole had been unmarled.* Hence he adds, if the occupier of the unmarled field would not have a succession of poor crops, he must marl *his* land also.*

Can it really be that nature thus rewards the diligent and the improver? Do the plants which grow on a soil in higher condition take from the air more than their due share of the carbonic acid or other vegetable food it may contain, and leave to the tenants of the poorer soil a less proportion than they might otherwise draw from it? How many interesting reflections does such a fact as this suggest! What new views does it disclose of the fostering care of the great Contriver—of his kind encouragement of every species of virtuous labour! Can it fail to read to us a new and special lesson on the benefits to be derived from the application of skill and knowledge to the cultivation of the soil?

* Wenn nämlich auf einer Feldflur Stück um Stück gemergelt worden ist, so wachsen die Früchte auf den nicht gemergelten Feldern, auch wenn hier alle früheren verhältnisse ganz die-selben bleiben, nicht mehr so gut, als ehedem; wodurch die Besitzer jener Felder, wenn sie nicht fortwährend geringe Erndten haben wollen, genöthigt sind, gleichfalls zu mergeln. Aus dieser höchst vichtigen Erscheinung, die man *sehr häufig* in Holsteinschen bemerkt, &c.—Sprengel, *Chemie für Landwirthschaft*, I., p. 303.

LECTURE VI.

Substances of which plants chiefly consist—Woody fibre, Starch, Gum, Sugars—Their mutual relations and transformations—Gluten, Vegetable Albumen, Diastase—Acetic, Tartaric, Malic, Citric, and Oxalic Acids—General observations.

FROM what has been stated regarding the structure of plants, it will be understood in what way the food is introduced into their circulation. The next inquiry appears to be *how*—by what chemical changes—is the food, when introduced, converted into those substances of which plants chiefly consist. But in order that we may clearly understand this point, it is necessary that we know first the nature and chemical constitution of the substances which are most largely formed from the food in the interior of the plant. To this point, therefore, I must previously direct your attention.

If you were to collect all the varieties of plants which are within your reach—whether such as are cultivated and used for food—or such as grow more or less abundantly in a wild state—and were to extract their several juices, and to separate from each of these juices the chemical compounds it contains—you would gradually gather together so many different substances, all possessed of different properties, that you would scarcely be able to number them.

But if at the same time you compared the weight of each substance thus collected with that of the entire plant from which it is derived, you would find also that the quantity of many of them is comparatively so minute that only a very small portion of the vital energies of the plant can be expended in producing them,—that they may be entirely neglected in a general consideration of the great products of vegetation. Thus though quinine and morphine, the active ingredients in Peruvian bark and in opium, are most interesting substances, from their effect upon the human constitution, and their use in medicine, yet they form so small a fraction of the mass of the entire trees or plants from which they are extracted, that it would be idle to attempt to convey to you any notion of the way in which plants grow and are fed, by showing you how such substances as these are produced from the food on which plants live.

While, however, the examination would satisfy you that almost every species of plant produced in small quantity one or more substances peculiar to itself, you would observe, at the same time, that every plant yielded a certain quantity of two or three substances common to and produced by all, and in most cases constituting the greater portion of their bulk. Thus all trees and herbs produce wood or woody fibre, and of this substance you know that their chief bulk consists. Again, all the grains and roots you cultivate contain starch in large quantity, and the production of this starch is one of the great objects of the art of culture. The juices of trees, and of grasses, and of cultivated roots, contain sugar and gum, and sometimes in such quantity as to make their extraction a source of profit both to the grower and to the

manufacturer. The flour of grain contains sugar also, and along with it two other substances, in small quantity, *gluten* and *vegetable albumen*, which are of much importance in reference to the nutritive qualities of the different varieties of flour. Sugar is also present in the juices of fruits, but it is there associated with various acid (sour) substances which disappear to a certain extent or change into sugar as the fruit ripens.

Of these few substances the great bulk of vegetables of all kinds consists. They constitute nearly the whole mass of those various crops which the art of culture studies to raise for the use of man and beast. To the study of these substances, therefore, I shall at present confine your attention, and if I shall afterwards be able to make you understand how these few compound bodies are produced in the interior of a plant from the food it takes up, I shall succeed in conveying to you as much information in regard to this most interesting branch of our subject as will be necessary to a general explanation not only of the natural growth and increase of plants, but of the nature and efficacy of those artificial means which the practical farmer employs, in order to hasten their growth or enlarge their increase.

§ 1. *Woody fibre or lignin—its constitution and properties.*

1°. When a portion of the stem of a herbaceous plant, or of the newly cut wood of the trunk or branch of a tree, is reduced to small pieces, and boiled in successive portions of water and alcohol, as long as any thing is taken up, a white fibrous mass remains, to which the name of woody fibre or lignin has been given. This substance has no taste or smell, and is perfectly insoluble in water. It is nearly identical in its chemical constitution and properties, whether it be obtained from the porous willow, or from the solid box tree, and the fibres of linen and of cotton consist essentially of the same substances.

According to the analysis of Dr. Prout, this woody fibre when dried at 350° F., consists of

	From Box Wood.	From the Willow.
Carbon	50·0	49·8
Hydrogen	5·55	5·58
Oxygen	44·45	44·62
	100	100

It will be recollected that water consists of oxygen and hydrogen, combined in the proportion, by weight, of 8 of the former to 1 of the latter. (See Lecture II., p. 36.) Now if the hydrogen above given be multiplied by 8, the product will be found to be almost exactly the weight of the oxygen given—since

$$5{\cdot}55 \times 8 = 44{\cdot}40, \text{ and}$$
$$5{\cdot}58 \times 8 = 44{\cdot}64.$$

In woody fibre, therefore, the hydrogen and oxygen exist in the same proportion as in water, and its composition, therefore, might be represented by

Carbon	50·0
Water	50·0
	100

did we not know that woody fibre, when heated or distilled, cannot be resolved into carbon (charcoal) and water *alone*, and, therefore, cannot be supposed to *consist* of these alone.

It is a remarkable character of this substance, however, that these two elements, hydrogen and oxygen, exist in it in the proportions to form water, and we shall find the knowledge of this fact of great importance to us, when we come to inquire how this constituent of vegetables is formed—from the food on which they live.

2°. If a portion of the wood of a tree be dried and analyzed *without* being previously digested in water, alcohol, and ether, as long as any thing is taken up, the proportion of the constituents is found to vary slightly with the species of tree, but in all cases the hydrogen is in larger quantity than is necessary to form water with the oxygen they contain. Thus, according to Payen, the dry wood of the following trees consists of

	Ebony.	Walnut.	Oak.	Beech.
Carbon . . .	52·85	51·92	50·00	49·25
Hydrogen . .	6·00	5 96	6·20	6·10
Oxygen . . .	41·15	42·12	43·80	44·65
	100	100	100	100

The carbon in these several kinds of wood differs as much as three per cent., but in each of them the product of the hydrogen, when multiplied by 8, is considerably greater than the per centage of oxygen.

3°. When the solid substance of wood is examined under the microscope it is observed to consist of two portions or kinds of matter, that of which the original sides of the cells and tubes is composed, called the *cellular matter*—the true woody fibre—and of a solid substance by which the cells are internally coated and strengthened, called the *incrusting matter*. It is in this latter substance that the excess of hydrogen, exhibited by the preceding analysis, is supposed to exist, the true woody fibre containing always the hydrogen and oxygen in the proportions necessary to form water.*

* Payen at first considered this *incrusting* matter as a peculiar substance, for which he proposed the name of *sclerogene*. His first mode of separating it from the cellular matter was by treating the finely rasped wood (of the oak and beech) with nitric acid, which dissolved out the incrusting matter and left the cellular matter behind. His second mode was to digest the wood with dilute sulphuric acid, by which the cellular matter was dissolved out, and the incrusting matter left. It is obvious, however, that no reliance whatever can be placed on the analyses of substances so treated, since they cannot fail to have undergone a chemical change by being exposed to the action of these strong acids. Further examination has satisfied Payen that the incrusting matter consists of at least *three* substances, of which one is soluble in water, alcohol, and ether, another in alcohol only, while the third is insoluble in any of these liquids. They are composed, according to his analyses, of

	Insoluble.	Soluble in alcohol only.	Soluble in water and alcohol.
Carbon . . .	48	52·8	68·58
Hydrogen . . .	6	5·9	7·04
Oxygen . . .	46	31·3	24·43[1]
	100	100	100

It is impossible to say how far the substances analysed by Payen are to be considered as pure, or as actually existing in the pores, or in the incrusting matter of the woody fibre, but it is obvious that the presence of a variable quantity of such substances will necessarily cause that excess of hydrogen, in the entire wood, which appears in the analysis of the ebony, walnut, oak, and beech woods, given in the text. That such an excess of hydrogen above what is necessary to form water with the oxygen, does exist in the wood of most trees

[1 Meyen's *Jahresbericht*, 1839, p. 10.]

It is exceedingly difficult in any case to separate the cellular from the incrusting matter of wood, so as to obtain the means of determining by analysis the exact difference in their elementary constitution. Under the impression that in very light and porous substances he should obtain the cellular matter in a purer form, Payen analysed the fibre of cotton—the pith of the elder, the cellular substance of the cucumber, of the mushroom, and of other fungi, the spongy matter which forms the extremities of the roots of plants, and various other similar substances, and in all these varieties he found the hydrogen and oxygen to exist in the proportions to form water. The mean of his analyses was very nearly as follows—which for the purpose of comparison I shall contrast with that of Dr. Prout:

	Woody fibre of box and willow—Dr. Prout.	Cellular matter of vascular plants—Payen.
Carbon . . .	50·00	44·80
Hydrogen . .	5·55	6·20
Oxygen . . .	44·45	49·0
	100	100*

In both these analyses the hydrogen is very nearly 8 times that of the oxygen. All these substances, therefore, may be represented by carbon and water, though the woody fibre of Dr. Prout contains 5 per cent. more carbon than the cellular matter of Payen.

If we calculate the number of equivalents of each element contained in these two varieties† of vegetable fibre composed as above exhibited, we find in the one 12 of carbon, 8 of hydrogen, and 8 of oxygen; in the other, 12 of carbon, 10 of hydrogen, and 10 of oxygen. They may, therefore, be conveniently represented by the following formulæ:

WOODY FIBRE . . . . . by $C_{12}\ H_8\ C_8$

CELLULAR FIBRE. . . . by $C_{12}\ H_{10}\ C_{10}$

It is not unlikely that both of these forms of matter may exist, as well in the perfect wood of trees as in the less consolidated pith of the elder, or in the fibres of cotton—and that they may occur intermingled also in varying proportions with other substances, containing hydrogen in excess.‡

in its natural state, is a fact to which it will be important to advert when we consider hereafter the chemical changes which the food undergoes in the interior of the plant.

* Meyen's *Jahresbericht*, 1839, p. 10.

† This is done very simply by dividing the carbon by 6, and the oxygen by 8 (see page 36), thus—

Carbon . . .	50 ÷ 6 = 8·33	which numbers	12
Hydrogen . .	5·55 = 5·55	are to each	8
Oxygen . . .	44·45 ÷ 8 = 55·5	other as	8

‡ The existence of a variety of cellular fibre identical in constitution with common starch, as this of Payen is, (see subsequent section, p. 106,) was previously rendered probable by the observations of Dr. Schleiden, that the embryo of the *Schotia latifolia*, consisting of pores and vessels, the sides of which exhibit distinct concentric layers, is entirely soluble in water, with the exception of the outer rind; and that its solution becomes blue on the addition of iodine. It would appear as if the cellular substance were in this case wholly composed of Starch. (*Poggendorf's Annalen*, xliii., p. 398.) It may, however, be in such a state of tenuity in the embryo of this plant, as to be easily changed into starch by the action of hot water; and it is still by no means certain that the cellular fibre analyzed by Payen may not also have undergone a change by the treatment to which it was previously subjected. I am unable, however, to speak decidedly on this subject, as I have not seen the details of M. Payen's several papers. (See subsequent section, *on the mutual transformations of woody fibre, starch, gum, and sugar*, p. 112.)

I have spoken of these varieties of woody fibre as constituting a large portion of the entire mass of vegetable matter produced during the growth of plants. That such is the case in the more gigantic vegetable productions, of which the great forests consist, is sufficiently evident, and so far the general statement is easily seen to be correct. It is also true of the dried stalks of the grasses and the corn-growing plants, of which it forms nearly one-half the weight,—but in roots and some plants which are raised for food, the quantity of woody fibre, especially in the earlier stages of their growth, is comparatively small.* Thus in the beet root it forms only 3 per cent. of the whole weight when taken from the ground. If suffered to remain in the soil till it becomes old, or if the growth be very slow, the beet becomes more woody, as many other roots do, and the quantity of ligneous fibre increases.

§ 2. *Starch—its constitution and properties.*

Next to woody fibre, starch is probably the most abundant product of vegetation. To the agriculturist it is a substance of much more interest and importance than the woody or cellular fibre, from the value it possesses as one of the staple ingredients in the food of man and animals—and from its forming a large portion of the weight of the various grains and roots which are the principal objects of the art of culture.

1°. When the flour of wheat, barley, oats, Indian corn, &c., is mixed up into a dough with water, and this dough washed on a linen cloth with pure water, a milky liquid passes through, from which, when set aside, a white powder gradually falls. This white powder is the *starch* of wheaten or other flour.

2°. When the pith of the sago palm is washed, in a similar manner, with water upon a fine sieve, a white powder is deposited by the milky liquid which passes through. This, when collected, forced through a metal sieve to granulate (or corn) it, and dried by agitation over the fire, is the *sago* of commerce.

* The following table shows the per centage of woody fibre contained in some common plants in the green state, and when dried in the air, and at 212°:

	Dried in the air. per cent.	IN THE GREEN STATE. Dried at 212°. per cent.	Woody fibre. per cent.	Water. per cent.
Barley straw, ripe	50	—	—	—
Oat straw, do.	—	47	—	—
Maize straw, do.	24	—	—	—
Stalks of the field pea	—	—	10½	80
Field bean straw	51	—	—	—
White turnip	—	—	3	92
Common beet (beta vulgaris)	—	—	3	86
Young twigs of common furze	—	—	24	50
Rape straw, ripe	—	55	12½	77
Tare straw, do.	37	—	—	—
Vetch plant (v. sativa)	42	—	10½	77½
Do. (v. cracca) in flower	—	—	5½	66
Do. (v. narbonensis) do.	—	—	11½	80
White lupin, in flower,	—	—	7	86
Lucerne, in flower,	—	—	9	73
Rye grass, do.	—	—	11	68
Red clover, do.	—	—	7	79
White clover, do.	—	—	4½	81
Trefoil (medium) do.	—	—	8½	73
Sainfoin (esparsette)	—	—	7	76
Trefoil (agrarium) in flower	—	—	12	68
Do. (rubens) do.	—	—	15	69

3°. When the raw potato is peeled and grated on a fine grater, and the pulp thus produced well washed with water, *potato starch* is obtained in the form of a fine white powder, consisting of rounded, glossy and shining particles.

4°. When the roots of the *Maranta Arundinacea* of the West India Islands are grated and washed like the potatoe, they yield the *arrow root* of commerce. From the root of the Manioc, the *cassava* is procured by a similar process, and this, when dried by agitation on a hot plate, is the *tapioca* of the shops. By this method of drying, both sago and tapioca undergo a partial change, which will be explained in a subsequent section (see p. 113.)

The substances to which these several names are given are, when pure, similar in their properties, and identical in their chemical constitution. They are all colourless, tasteless, without smell, when dry and in a dry place may be kept for any length of time without undergoing alteration, are insoluble in cold water or alcohol, dissolve readily in boiling water, giving a solution which gelatinizes (becomes a jelly) on cooling—and in a cold solution of iodine* they all become blue.

When dried at 212°, they consist, according to Dr. Prout, with whose analysis those of other chemists agree, of

Carbon	44·0 per cent.,	or 12 atoms.
Hydrogen	6·2 per cent.,	or 10 atoms.
Oxygen	49·8 per cent.,	or 10 atoms.
	100	

Starch, therefore, may be represented by the formula $C_{12}\ H_{10}\ O_{10}$, which is identical with that deduced in the preceding section for the *cellular fibre* of Payen. Both substances, therefore, contain the same elements (carbon, hydrogen and oxygen), united in the same proportions, and in both, as well as in the common fibre of wood, the hydrogen and oxygen exists in the proportion to form water.

That starch constitutes a large portion of the weight of grains and roots, usually grown for food, will appear from the following table, which exhibits the quantity present in 100 lbs. of each substance named:

	Starch per cent.
Wheat flour	39 to 77
Rye "	50 to 61
Barley "	67 to 70
Oatmeal	70 to 80
Rice flour	84 to 85
Maize "	77 to 80
Buckwheat	52
Pea and Bean meal	42 to 43
Potatoes, containing 73 to 78 of water, .	13 to 15

It thus exists most largely in the seeds of plants, and in some roots. It is frequently deposited, however, among the woody fibre of certain trees, as in that of the willow, and in the inner bark of others, as in

* Iodine is a solid substance, of a lead-grey colour, possessed of a peculiar powerful odour, and forming when heated a beautiful violet vapour. It exists in small quantity in sea water, and in some marine plants. Its solution in water readily shows the presence of starch, by the blue colour it imparts to it.

those of the beech and the pine.* Hence the readiness with which a branch of the willow takes root and sprouts, and hence also the occasional use of the inner bark of trees for food, especially in northern countries, and in times of scarcity. In some roots which abound in sugar, as in those of the beet, the turnip, and the carrot, only 2 or 3 per cent. of starch can be detected.

§ 3. *Gum—its constitution and properties.*

The variety of gum with which we are most familiar is *gum arabic*, or *senegal*, the produce of various species of *acacia*, which grow in the warmer regions of Asia, Africa, and America. It exudes from the twigs and stems of these trees, and collects in rounded more or less transparent drops or tears. It is also produced in smaller quantities in many of our fruit trees, as the apple, the plum, and the cherry; it is present in some herbaceous plants, as in the althæa and malva officinalis (common and marsh mallow); and it exists in lint, rape, and many other seeds. When treated with boiling water these plants and seeds give mucilaginous solutions.

Many varieties of gum occur in nature, but they are all characterised by being insoluble in alcohol, by dissolving or becoming gelatinous in hot or cold water, and by giving *mucilaginous*—viscid and glutinous—solutions, which may be employed as a paste.

Three distinct species of gum have been recognised by chemists:

1°. *Arabin*—of which gum arabic and gum senegal almost entirely consist. It is *readily soluble in cold water*, giving a viscid solution, usually known by the name of the *mucilage* of gum arabic.

2°. *Cerasin*—which exists in the gum of the cherry-tree. It is *insoluble in cold water*, but *dissolves readily in boiling water*. When thus dissolved it may be dried without losing its solubility, and is therefore by boiling supposed to be changed into arabin.

3°. *Bassorin*—existing in what is called *bassora gum*—and forming a large portion of gum tragacanth.† It *swells and becomes gelatinous in cold water, but does not dissolve in water either cold or hot.*

By these characters, the three kinds of gum are not only readily distinguished, but may be easily separated from each other. Thus if a native gum or an artificial mixture contain all the three, simple steeping in and subsequent washing with *cold* water, will separate the *arabin*—boiling water will then take up the *cerasin*, and the *bassorin* will remain behind.

These different kinds of gum all possess the same chemical constitution. According to the analyses of Mulder, they consist of

Carbon . . .	45·10	per cent.,	or 12 atoms.
Hydrogen . .	6·10	"	or 10 "
Oxygen . . .	48·80‡	"	or 10 "
	100		

* Its presence is readily detected in such wood by a drop of the solution of iodine—which gives a permanent blue to starch, but to the woody fibre only a brownish stain.

† This gum exists along with starch in the roots of the various species of *orchis*, especially of those which are used for making *salep* (Meyen).

‡ Berzelius *Arsberättelse*, 1839, p. 443.

In these analyses, as in those of starch and woody fibre, we see that the per centage of oxygen is equal to that of the hydrogen multiplied by 8, and consequently that these two elements are, as already stated, in the proportion to form water. But we see also that the carbon is in the proportion of 12 atoms or equivalents to 10 of each of the other constituents, and therefore gum may be represented by $C_{12} H_{10} O_{10}$—a formula which is identical with that already given for starch and cellular fibre.

It appears, therefore, that not only may *gum*, *starch*, and *cellular fibre* be represented by carbon and water, but that they *all consist of carbon and the elements of water, united together in the same proportions.*

Gum not only exists in many seeds, and exudes as a natural product from the stems and twigs of many trees, but is also contained in the juices of many other trees, from which it is not known to exude; and in the sap of most plants it may be detected in greater or less quantity. It may be considered, indeed, as one of those substances which are produced most largely and most abundantly in the vegetable kingdom, since, as will hereafter appear, it is one of those forms of combination through which organic matter passes in the interesting series of changes it undergoes during the development and growth of the plant.

§ 4. *Of Sugar—its varieties and chemical constitution.*

1°. *Cane Sugar.*—Sugar, identical in constitution and properties with that obtained from the sugar-cane, and generally known by the name of *cane*-sugar, exists in the juices of many trees, plants, and roots. In the United States of North America the juice of the maple tree is extensively collected in spring, and when boiled down yields an abundant supply of sugar. In the Caucasus that of the walnut is extracted for the same purpose. The juice of the birch also contains sugar, and it may be obtained, in lesser quantity, from the sap of many other trees. In the juice of the turnip, carrot, and beet, it is also present, and in France and Germany the latter root is extensively cultivated for the manufacture of beet sugar. In the unripe grains of corn, at the base of the flowers of many grasses and clovers when in blossom, and even in many small roots, as in that of the quicken or couch-grass (triticum repens), the presence of sugar may likewise be readily detected.

Sugar is principally distinguished by its agreeable sweet taste. When pure, it is colourless and free from smell. It dissolves readily in alcohol and in large quantity in water. The solution in water, when much sugar is present, has an oily consistence, and is known by the name of *syrup*. From this syrup the sugar gradually deposits itself in the form of *sugar candy*. If the syrup be boiled on too hot a fire, it chars slightly, becomes discoloured, and a quantity of *molasses* is formed. Pure *cane*-sugar, free from water, consists of

Carbon . . .	44·92	per cent.,	or 12 atoms.
Hydrogen . .	6·11	"	or 10 "
Oxygen . . .	48·97	"	or 10 "
	100		

If we compare these numbers with those given for starch and gum in the preceding sections, we see that they are almost identical—so that

cane-sugar also contains oxygen and hydrogen in the proportions to form water, and may likewise be represented by the formula $C_{12}\ H_{10}\ O_{10}$.

2°. *Grape sugar.*—In the juice of the grape a peculiar species of sugar exists, which, in the dried raisin, presents itself in the form of little rounded grains. The same kind of sugar gives their sweetness to the gooseberry, the currant, the apple, pear, plum, apricot, and most other fruits. It is also the sweet substance of the chesnut, of the brewers' wort, and of all fermented liquors, and it is the solid sugar which floats in rounded grains in liquid honey, and which increases in apparent quantity as the honey, by keeping, becomes more and more solid.

Grape sugar has nearly all the sensible characters of cane sugar, with the exception of being less soluble in water and also less sweet,—2 parts of the latter imparting an equal sweetness with 5 of the former.

In chemical constitution they differ considerably. Thus grape sugar dried at 250° F., consists of

Carbon . . .	40·47	per cent.,	or 12 atoms.
Hydrogen . .	6·59	"	or 12 "
Oxygen . . .	52·94	"	or 12 "
	100		

The oxygen here is still eight times greater than the hydrogen, and, therefore, in this variety of sugar also, these elements exist in the proportions to form water. But for every 12 equivalents of carbon, dry grape sugar contains 12 of hydrogen and 12 of oxygen. It is consequently represented by $C_{12}\ H_{12}\ O_{12}$, and contains the elements of two atoms of water ($H_2\ O_2$) more than cane sugar.*

3°. *Manna sugar, sugar of liquorice, &c.*—Besides the cane and grape sugars which occur in large quantity in the juices of plants, there are other varieties which occur less abundantly, and are therefore of less interest in the study of the general vegetation of the globe. Among these is *manna*, which partly exudes and is partly obtained by incisions from certain species of the *ash* tree which grow in the warmer countries of Southern Europe (Sicily and Italy), and in Syria and Arabia. It also exists, it is said, in the juice of the larch tree, of common celery, and of certain trees which are met with in New South Wales. Liquorice root also contains a species of *black* sugar, which is known in this country under the names of Spanish and Italian juice, from the countries where it is grown. In the mushroom and other *fungi* a colourless variety, apparently peculiar, has also been met with,—and milk owes its sweetness to a species of sugar formed in the interior of the animal along with the other substances which the milk contains.

These several kinds of sugar differ more or less, not only in sensible and chemical properties, but also in chemical constitution, from the more abundant cane and grape sugars—but they form too small a part of the general products of vegetation, and are of too little consequence in practi-

* Solutions of cane and grape sugar are readily distinguished from each other by the following chemical characters:—1. If the solution be heated and a few drops of sulphuric acid then added, cane sugar will be decomposed, blackened, and made to fall as a black or brown powder—while a solution of grape sugar will at the most be only slightly discoloured. 2. If, instead of sulphuric acid, caustic potash be employed, the cane sugar will be unchanged, while the grape sugar will be blackened and thrown down.

cal agriculture to render it necessary to do more than thus shortly advert to their existence.*

§ 5. *Mutual relations of woody fibre, starch, gum, and sugar.*

It may be interesting now to consider for a moment the mutual relations of the several substances, woody fibre, starch, gum, and sugar—above described—which occur so largely in the vegetable kingdom, and are serviceable to man for so many different purposes. These relations will be best seen on comparing the formulæ by which they are respectively represented. Thus—

WOODY FIBRE	(lignin)	is represented by	$C_{12}\ H_8\ O_8$
CELLULAR FIBRE	(according to Payen)	by	$C_{12}\ H_{10}\ O_{10}$
STARCH	(dried at 212° F.)	by	$C_{12}\ H_{10}\ O_{10}$
GUM	(any of the 3 varieties)	by	$C_{12}\ H_{10}\ O_{10}$
CANE SUGAR	(free from water)	by	$C_{12}\ H_{10}\ O_{10}$*
GRAPE SUGAR	(dried at 130° F.)	by	$C_{12}\ H_{12}\ O_{12}$†

In these formulæ we observe—

1°. That the eqivalents of the oxygen are equal to those of the hydrogen in *all* the formulæ, and, therefore, that all these substances may be *supposed* to consist of carbon and water.

2°. The formulæ for cellular fibre, starch, gum, and cane sugar, are identical. *They consist of the same elements united together in the same proportions.*

This is one of those facts which not only appear very remarkable to the unlearned, but are scarcely capable of being clearly comprehended and explained, even by those who have most profoundly studied this branch of natural science. Starch and sugar—how different their properties! how unlike their uses! how unequal their importance to the human race! yet they consist of the same weights of the same substances, differently conjoined. The skilful architect can put together the same proportions of the same stone and cement—and the painter can combine the same colours so as to produce a thousand varied impressions on the sense of sight. In the hand of Deity matter is infinitely more plastic. At His bidding the same particles can unite in the same quantity so as to produce the most unlike impressions—and on *all* our senses at once.

3°. A knowledge of the above close relations in composition, among a class of substances occurring so abundantly in the vegetable kingdom, imparts a degree of simplicity to our ideas of this otherwise complicated subject. It does not appear so mysterious that we should have woody fibre, and starch, and gum, and sugar, occurring together in variable quantities, when we know that they are all made up of the same materials, in the same or nearly the same proportions—or that one of these should occasionally disappear from a plant, to be replaced in whole or in part by another.

* For a list of plants from which sugar has been extracted, see Thomson's *Organic Chemistry* (1838), p. 647.

† Crystallized cane sugar (sugar candy) loses 5·3 per cent. of water in favourable circumstances. This is equal to one equivalent (HO), so that if dry sugar be $C_{12}\ H_{10}\ O_{10}$, crystallized sugar is $C_{12}\ H_{11}\ O_{11}$—or $C_{12}\ H_{10}\ O_{10}+HO$, since there is no doubt that this one equivalent of the hydrogen and oxygen exists in crystallized sugar in the state of water. In like manner, crystallized honey or grape sugar—as it occurs in honey or in the dried grape—loses 9 per cent. of water when heated to 250° F. This is equal to two equivalents (2HO), so that crystallized grape sugar is represented by $C_{12}\ H_{14}\ O_{14}$ or $C_{12}\ H_{12}\ O_{12}+2HO$.

A further question, however, arises in our minds. We naturally ask, —does nature, in thus removing one of these compounds, and supplying its place by another, actually form from its elements the new substance introduced, or does she produce it by a mere change or transformation of those previously existing. A satisfactory reply to this question may be derived from the facts detailed in the following section.

§ 6. *Mutual transformations of woody fibre, starch, gum, and sugar.*

I.—WOODY FIBRE.

1°. *Action of heat.*—If wood be reduced to the state of fine saw-dust, be then boiled in water to separate everything soluble, afterwards dried by a gentle heat, and then heated several times in a baker's oven, it will become hard and crisp, and may be ground in the mill into a fine meal. The powder thus obtained is slightly yellow in colour, but has a taste and smell similar to the flour of wheat; it ferments when made into a paste with yeast or leaven, and when baked gives a light homogeneous bread. Boiled with water, it yields a stiff tremulous jelly, like that from starch (Autenrieth.—Schübler, *Agricultur Chemie*, i., p. 224.) By the agency of heat, therefore, it appears that the *woody fibre may be changed into starch.*

2°. *Action of sulphuric acid.*—If to three parts of the sulphuric acid of the shops (oil of vitriol) one part of water be added, and a portion of delicate woody fibre be immersed in it for half a minute, and the whole then rubbed in a mortar with a few drops of a solution of iodine—the woody fibre will assume a *blue colour*, showing that it is in part at least *changed into starch** (Schleiden).

Again, if three parts of fine saw-dust or of fragments of old linen be rubbed in a mortar with four of the sulphuric acid of the shops added by degrees—it will, in a quarter of an hour, be rendered completely soluble in water. If the solution in water be freed from acid by chalk, and then evaporated, a substance resembling gum arabic is obtained (Braconnot). According to Schleiden, the fibre may be seen under the microscope gradually to change from without inwards, first into starch and then into gum.

Further, if this gum be digested with a second portion of sulphuric acid diluted with 8 or 10 times its weight of water, it will be gradually converted into *grape sugar;* or the fibre of wood or linen may be changed directly into sugar by the prolonged action of dilute sulphuric acid.

3°. *Action of potash.*—If saw-dust be mixed with from two to eight times its weight of hydrate† of potash and as much water, and boiled till a crust forms on the surface, and if dilute sulphuric acid be then added till the whole is slightly sour, the undestroyed woody fibre will give an

* It will be recollected that starch is characterized by giving a blue colour with a solution of iodine (see p. 107).

The simplest way of trying this experiment is, to take a quantity of clean cotton—to wet it with water, squeezing out again as much as possible—then to spread it out upon a flat dish and moisten it quickly and thoroughly with the acid diluted as above. After half a minute, add the solution of iodine, stir quickly with a glass rod, and immediately add water, when the blue compound of iodine and starch will speedily deposit itself.—(Schleiden, *Pog. Annal.*, xliii., p. 396.)

† Hydrate of potash is the caustic substance which is obtained by boiling common pearlash with quick-lime.

instantaneous deep blue on the addition of iodine, showing that starch has been formed.

Woody fibre, therefore, may be changed into starch, either by the unaided action of heat, by that of sulphuric acid, or by boiling with caustic potash,—and the starch thus produced may be further transformed, first into gum and then into grape sugar, by the prolonged action of dilute sulphuric acid, assisted by a moderate heat.

II. STARCH.

1°. *Action of heat.*—When flour, potato, or arrow-root starch is spread out upon a tray, then introduced into an oven and gradually heated to a temperature not exceeding 300° F., it slowly changes, acquires a yellow or brownish tint according to the temperature employed, and becomes entirely soluble in cold water. *It is changed into gum.* Under the names of starch-gum, or British-gum, this substance is largely manufactured in this country, and is successfully substituted for gum arabic by the calico-printers in thickening many of their colours.*

The gum thus prepared not unfrequently also possesses a sweet taste, from the further change of a portion of the gum into sugar.

2°. *Action of water.*—When starch is dissolved in boiling water, and is then allowed to stand in the cold either in a close vessel or exposed to the air, it gradually changes into gum or sugar. The process, however, is slow, and months must elapse before the whole of the starch is thus spontaneously transformed in the presence of water (De Saussure). It takes place more rapidly when starch and water are boiled together for a length of time.

3°. *Action of sulphuric acid.*—From what has been already stated in regard to the action of this acid on woody fibre it will readily be supposed that native starch, of any variety, is likely to undergo transformation when subjected to its influence.

In reality, if 50 parts of starch, 12 of sulphuric acid, and 139 of water be taken, and if the starch be thoroughly moistened with a portion of the water, and then poured into the mixture of the acid with the remainder of the water, and heated to 190° F., the starch will be entirely converted into gum. By further and more prolonged heating this gum is changed into grape sugar. The gum or sugar may be obtained in a separate state by adding to the solution either chalk or lime, which will combine with and carry down the acid.† One hundred pounds of starch treated in this way will yield from 105 to 122 lbs. of dry grape sugar.

The rapidity with which this transformation takes place depends partly upon the temperature and partly upon the proportion of acid employed. Thus 100 lbs. of starch mixed with 600 of water and 10 of sulphuric acid, will be converted into grape sugar by boiling for *seven* hours. If by increasing the pressure the temperature be raised to 250° F., the transformation will be effected in a *few minutes.* With only one

* During the baking of bread this conversion of starch into gum takes place to a considerable extent. Thus Vogel found that flour which contained no gum gave, when baked, a bread of which 18 per cent., or nearly one fifth of the whole weight, consisted of gum. Thus one of the effects of baking is to render the flour-starch more soluble, and therefore (?) more easily digestible.

† It forms *gypsum* with it (sulphate of lime) which is a compound of lime and sulphuric acid.

pound of acid and the same quantity of starch and water, the change will be effected in *three* hours by a temperature of 230° F. This mode of converting potato starch into grape sugar is said to be extensively practised in France, for the purpose of subsequently fermenting the sugar and converting it into *brandy*.

III. GUM.

Action of sulphuric acid.—If powdered gum arabic be rubbed in a mortar with the sulphuric acid of the shops, a brownish solution is obtained, which, when diluted with water and treated with chalk, yields a gummy substance similar to that obtained in the same way from starch and woody fibre. Prolonged digestion with diluted acid converts a portion of this gum into sugar.—[Berzelius, *Traité de Chemie*, (1831), v., p. 217.]

IV.—CANE SUGAR.

1°. *Action of heat.*—When crystallized cane sugar is heated to 320° F. it melts, and if the temperature be raised to 360° F. it gives off two atoms of water and is changed into *caramel*. This caramel is an uncrystallizable sugar, which is generally present in artificial syrups, and is often of a brownish colour. It contains the elements of an atom of water less than cane sugar, and is represented by $C_{12} H_9 O_9$. It is not known to occur in the natural juices of plants.

2°. *Action of sulphuric acid.*—When cane sugar is digested with dilute sulphuric acid, aided by a gentle heat, it is rapidly converted into grape sugar. The acid of grapes (tartaric acid) and many other vegetable acids produce a similar change.

It is obvious that this conversion of cane into grape sugar can only take place in the presence of water, inasmuch, as has already been shown (p. 110), grape sugar contains the elements of two atoms of water more than cane sugar, or

$$\underset{\text{Cane sugar.}}{C_{12} H_{10} O_{10}} + \underset{\text{Water.}}{2HO} = \underset{\text{Dry grape sugar.}}{C_{12} H_{12} O_{12}}.$$

We may revert now to the question with which we concluded the preceding section. Since these different substances are so closely allied in chemical constitution, and occur so often in connection with each other in the vegetable kingdom, does nature, when her purposes demand the change, actually transform them, the one into the other, in the interior of the plant? The answer may now be safely given, that she certainly does. What we can so readily perform by our rude art may be still more easily effected in the living vegetable. That which is starch or gum in one part of the plant, may become cane or grape sugar in another, and woody fibre in a third. Thus by re-arranging the same kind and quantity of the several elements, may the various and unlike forms of matter which constitute the main products of vegetation be readily produced.

Still the facility is only apparent. We can assure ourselves of the fact of such conversions, because we can at will induce them. But who operates upon these substances in the interior of the plant? Whose mind and will directs these changes—prescribing when, where, and in

what order they shall take place? How much depends upon the refined and little understood mechanism of the vegetable structure—how much on the living principle itself! What is this living principle—how can *it* direct!*

§ 7. *Of the fermentation of starch and sugar—and of the relative circumstances under which cane and grape sugars generally occur in nature.*

It will be of use to us, in connection with the above transformations, to advert to the property possessed by starch and nearly all the known varieties of sugar of entering into fermentation under favourable circumstances. When flour is made into a paste with leaven or yeast it begins to rise and ferment,—sooner or later, according to the kind of flour and the quantity of ferment added. When to a decoction of malt or to a solution of starch or of cane or grape sugar in water, a portion of yeast is added, fermentation is speedily induced; and if not arrested by unfavourable circumstances it will continue until the whole of the starch or sugar disappears.

In all these cases it is grape sugar alone that undergoes fermentation. [Rose, *Poggen. Annal.*, lii., p. 297.] The starch of the moist dough or of the solution is partially transformed into grape sugar before fermentation commences. Such is the case also with the decoction of malt and with cane sugar. The fermentation commences soon after the first portion of grape sugar is formed, and proceeds more or less rapidly according as this transformation is more or less speedily effected. Hence, in the art of brewing, the necessity of cautiously regulating the temperature by which this change of the starch and sugar is promoted and hastened.

The fermentation itself is the result not of a mere *transformation* of one form of matter into another having the same elementary constitution, but of a *decomposition* of one substance into two others unlike itself either in properties or in chemical composition. The grape sugar is resolved into alcohol (spirits of wine), which remains in the liquid, and into carbonic acid, which escapes in the form of gas and causes the fermentation. Thus alcohol being represented by $C_4\ H_6\ O_2$, and carbonic acid by CO_2,

2 of alcohol	$= C_8\ H_{12}\ O_4$ and
4 of carbonic acid	$= C_4\ \ O_8$ make up
1 of grape sugar	$= C_{12}H_{12}O_{12}$.

It is an interesting fact that the cane and grape sugars occur in nature in circumstances which are entirely consistent with the statement in the preceding section, regarding the action of acids on the former variety of this natural product. Fruits contain grape sugar, which increases in quantity as they ripen or become less sour. In the sugar cane, the beet root, and the maple and birch trees, cane sugar exists, but in their juices no acid is associated with the sugar. On the contrary, ammonia is known to be present in most of them along with the cane sugar. Hence it is inferred, that as in our hands and in our experiments cane sugar is changed by the agency of acids into grape sugar, and

* "Canst thou by searching find out God—Canst thou find out the Almighty unto perfection?"

with remarkable ease by that acid which exists in the ripe grape, so it is in the interior of plants. Where sugar occurs in connection with an acid in the juice of a plant, it is grape sugar in whole or in great part, because in the presence of an acid body cane sugar cannot permanently exist, but is gradually transformed into the sugar of grapes. It thus appears also why fruits so readily enter into fermentation, and why, even when preserved with cane sugar, they will, in consequence of the acid they retain, slowly change the latter into grape sugar, and thus induce fermentation.*

§ 8. *Of substances which contain Nitrogen.—Gluten, Vegetable Albumen, and Diastase.*

The substances described in the preceding sections consist of carbon, hydrogen, and oxygen only, and of them the great bulk of the vegetable productions of the globe consists. But there are certain other substances occurring along with starch and sugar, into which nitrogen enters as a constituent, and which, though not formed in the vegetable kingdom in very large quantity, are yet of such interest and importance in other respects, as to make it necessary shortly to advert to them.

1°. *Gluten.*—When the flour of wheat is made into a dough, and this dough is washed with water upon a fine sieve, a milky liquid passes through, from which starch gradually subsides. This has been already stated. But on the sieve, when the water ceases to go through milky, there remains a soft adherent, tenacious, and elastic substance, which can be drawn out into long strings, has scarcely any colour, taste, or smell, and is scarcely diminished by washing either with hot or with cold water. This substance is the *gluten* of *wheat*. The flour of other kinds of grain also yield it by a similar treatment, though generally in much smaller quantity. This appears from the following table :—

The grain of

Wheat contains	8 to 35	per cent. of	gluten.
Rye	9 to 13	"	"
Barley . . .	3 to 6	"	"
Oats	2 to 5	"	"

When the moist gluten is dried in the air or at the temperature of boiling water, it diminishes much in bulk, and hardens into a brittle semi-transparent yellow substance resembling horn or glue. In this state it is insoluble in water, but dissolves readily in vinegar, in alcohol either cold or hot, and in solutions containing caustic potash, or soda, [the common *pearl-ash* or *soda* of the shops boiled with quick-lime.]

2°. *Vegetable Albumen.*—To the white of egg the name of albumen (*albus*, white) has been given by chemists. It possesses the well known property of coagulating or of forming a white solid insoluble substance, when it is heated either alone or after being mixed with water.

When the starch has subsided from the milky liquid which passes

* Milk also, in favourable circumstances, as when kept at a temperature of 100° F., undergoes fermentation, and in some countries of Asia a spirituous liquor is prepared from mares' and asses' milk. In this case the milk first becomes sour, then the acid thus formed converts the milk sugar into grape sugar, and finally this sugar enters into fermentation. This takes place more readily in consequence of the presence of the decomposing cheesy matter (casein) of the milk—as is shown by the fact that the introduction of a small quantity of the curd of milk into a solution of grape sugar will cause it to ferment.

through the sieve in preparing the gluten of wheat, the water rests transparent and colourless above the white sediment. If this water be heated, it will become more or less troubled, and white films or particles will separate, which may be easily collected, and which possess all the properties of coagulated albumen, or boiled white of egg. To this substance the name of *vegetable albumen* has been given. When the fresh prepared *gluten* of wheat is boiled in alcohol a portion of albumen generally remains undissolved, showing that water does not completely wash it out from the gluten.

Vegetable albumen, when fresh and moist, has neither colour, taste, nor smell, is insoluble in water or alcohol, but dissolves in vinegar and in caustic potash or soda. When dry it is brittle, more or less coloured, and opaque. In the seeds of plants, it exists only in small quantity—thus the grain of

Wheat contains	$\frac{1}{4}$ to $1\frac{1}{2}$	per cent.
Rye . . .	2 to $3\frac{1}{4}$	"
Barley . . .	$\frac{1}{10}$ to $\frac{1}{2}$	"
Oats . . .	$\frac{1}{5}$ to $\frac{1}{2}$	"

It occurs more largely however in the fresh juices of plants, in those of cabbage leaves, turnip roots, and many others. When these juices are heated the albumen coagulates and is readily separated.

Gluten and vegetable albumen appear to be as closely related as sugar and starch are to each other. Like these two substances, they consist of the same elements, united together in the same proportions, and are capable of similar mutual transformations. According to the most recent analyses, those of Dr. Scheerer, they consist of

Carbon	= 54·76
Hydrogen	= 7·06
Oxygen	= 20·06
Nitrogen	= 18·12
	100

When exposed to the air in a moist state these substances undergo decomposition. They ferment, emit a most disagreeable odour, and produce, among other compounds, vinegar and ammonia.

The important influence which gluten and vegetable albumen are supposed to exercise over the nourishing properties of the different kinds of food in which they occur, will be considered in a subsequent part of these lectures.*

3°. *Diastase.*—When cold water is poured upon barley newly malted and crushed, is permitted to remain over it for a quarter of an hour, is then poured off, filtered, evaporated to a small bulk over boiling water, again filtered if necessary, and then mixed with much alcohol, a white tasteless powder falls—to which the name of *diastase* has been given.

* There occur in the animal kingdom—in the bodies of animals—three other forms of the substance above described under the names of gluten and vegetable albumen. These are albumen or white of egg, already mentioned,—*casein*, the curd of cheese,—and *fibrin*, the substance of the muscular fibre of animals.

1°. *Casein.*—When the curd of cheese is well washed with water, and then boiled in alcohol to free it from oily matter, it forms the casein of chemists. While moist it is soft and colourless, but as it dries it hardens, assumes a yellow colour, and becomes semitransparent. Even when moist it is perfectly insoluble either in cold or in hot water. It is solu-

If unmalted barley be so treated no diastase is obtained. This substance, therefore, *is formed during the process of malting.*

If wheat, or barley, or potatoes, which by steeping in water yield no diastase, be made to germinate (or sprout), and be afterwards bruised and treated as above, diastase will be obtained. *It is therefore produced during germination.*

If the shoot of a potato be cut off within half an inch of its base, this lower portion, with the part of the potato to which it is immediately attached, separated from the rest—and the three parts (the upper portion of the shoot—the lower portion with its attached fragment of potato—and the remaining mass of the potato) treated with water,—only that portion will yield diastase in which the base of the shoot is situated. When a seed sprouts, therefore, *this substance is formed at the base of the germ*, and there remains during its growth.

If the same portion of the potato, or if the grain of barley or wheat is

ble, however, in water containing vinegar, or to which a little carbonate of potash or soda has been added. It may be kept for any length of time in a dry place, without undergoing decay. The changes undergone by old cheese are chiefly due to the oily and other substances with which the curd is mixed. It has been remarked, that when the gluten of wheat is left for a length of time in a moist state it undergoes a kind of fermentation and gradually acquires the smell and taste of cheese (Rouelle.)

2°. *Fibrin.*—When lean beef or mutton is long washed in water till it becomes colourless, and is then boiled in alcohol to separate the fat, a colourless, elastic, fibrous mass is obtained, which is the fibrin of chemists. In recently drawn blood it exists in the liquid state, but coagulates spontaneously when exposed to the air, and forms the greater part of the *clot* of blood. It dissolves in a solution of caustic potash or of nitre, and in vinegar.

3°. *Albumen.*—This substance in the liquid state exists in the white of egg, and in the serum of the blood. It coagulates by heating to 160° F, or if previously mixed with water by raising to 212° F.

These three substances, in addition to their well known sensible properties, are distinguished as follows:

1°. *Liquid casein* in milk, is not coagulated by heating *alone*—the addition of rennet or of a little acid (vinegar or spirit of salt) is necessary, when it curdles readily.

2°. *Liquid albumen* in white of egg, coagulates by heat alone, as when an egg is put into hot water.

3°. *Liquid fibrin* in the blood coagulates by mere exposure to the air, or more rapidly by agitation in contact with the air.

Like starch and sugar these three substances are mutually convertible by known means. Thus *fibrin*, if unboiled, dissolves by digestion at 80° F. in a saturated solution of nitre, and acquires the properties of *liquid albumen;* and if to *liquid albumen* a little caustic potash be added, and afterwards much alcohol, it will be thrown down in the form and with the properties of *casein.*

All these substances appear to contain the same organic constituents in the same proportions.

Boussingault first showed the identity in chemical constitution of gluten and vegetable albumen.—[Pog. An., xl., p. 253.] Mulder afterwards proved a similar identity between vegetable albumen and the white of egg, fibrin, and casein.—[Ann. de Chim. et. de Phys., lxv., p. 301.] Mulder supposes them to differ from each other by the presence in unlike quantities of a small admixture of sulphur, phosphorus or phosphate of lime.

Those who are not familiar with the history and with the nature of chemical research, can form no idea of the time and labour which has by different chemists been expended on this one branch. The persevering industry of Dr. Mulder, of Rotterdam, appeared to have cleared up the entire subject by a long series of investigations and analyses,—[for an outline of his results, see Berzelius Arsberättlese, 1839, p. 611,]—when first Vogel, then Prosper Denis, and latest Liebig and Dr. Scheerer, have arrived at different results. Our ideas are thus again unfixed, and our partial generalizations set aside for future emendation.

The analysis inserted in the text, as representing the composition of gluten and vegetable albumen, is that given by Dr. Scheerer for the purest form of *fibrin.* I have selected it in preference to the results either of Boussingault or of Mulder, because it is the most recent, and has been obtained with a knowledge of all the previous researches,—and assuming the chemical identity of this entire group of substances, is the most likely to represent their constitution with accuracy. It differs from the analysis of Mulder *only* in stating the nitrogen at 2 per cent. higher than was done by that chemist. The recent improvements in the mode of determining the true quantity of nitrogen in organic substances, appear to justify us in expecting the result of Scheerer to be in this respect the more correct.

examined, when the first true leaves of the plant have been fully formed and expanded, the diastase will be found to have in great part, if not entirely, disappeared. This substance, therefore, is first formed when the seed begins to sprout, performs a function which makes its presence necessary at the base of the germ, and which function being discharged when the true leaves are formed, it then disappears. What is the nature of this temporary function, why the diastase must reside at the base of the sprout in order to discharge it, and why it should so early cease, will appear from a detail of the properties of this singular substance.

Properties of diastase.—If the solution obtained from malt be digested with potato, flour, or other starch, at a temperature between 120° and 140° F., the latter will gradually dissolve and will form a colourless transparent solution. When this solution is carefully evaporated a yellowish white powder is obtained, perfectly soluble in water, to which the name of *dextrine* has been given, [because its solution turns to the *right* a ray of polarized light when passed through it.] This dextrine has the same composition as starch. It is merely starch changed or transformed in such a way as to become soluble in cold water,—a change analogous to that which it undergoes by simply boiling in water.

But if the digestion be continued after the starch is dissolved, the solution will gradually acquire a sweet taste, and if it be now evaporated it will yield, instead of dextrine, a mixture of gum and grape sugar. And if the digestion be still further prolonged, the whole of the starch will be converted into grape sugar only.—[See above, § 6, p. 113.]

Thus *diastase* (like sulphuric acid) possesses the property of transforming starch entirely—first into gum, and then into grape sugar. The intermediate stage of dextrine has not been recognized in the action of sulphuric acid, nor is it easy to arrest the action of diastase exactly at this point—the most carefully prepared dextrine always containing a mixture of gum and sugar. One part of diastase will convert into sugar 2000 parts of starch.

A solution of diastase, when allowed to stand, soon undergoes decomposition, and after being boiled, it has no further effect upon starch. It has not been analysed, because it is difficult to obtain it in a pure state. It contains nitrogen, however, for, when moistened and exposed to the air, it decomposes, and, among other products, yields ammonia.*

The functions of diastase—one of the purposes at least for which it is produced in the living seed, and situated at the base of the germ—will now be in some measure understood. The starch in the seed is the food of the future germ, prepared and ready to minister to its wants whenever heat and moisture concur in awakening it to life. But starch is itself insoluble in water, and could not, therefore, accompany the fluid sap when it begins to move and circulate. For this reason diastase is formed at the point where the germ first issues from the mass of food. There it transforms the starch, and renders it soluble, so that the young vessels can take it up and convey it to the point of growth. When the starch is exhausted its functions cease. It is then itself transformed and

* It will be recollected that ammonia contains nitrogen, being represented by NH_3.—See Lecture III., p. 51.

carried into the general circulation. Or when, as in the potato, much more starch is present than is in many cases requisite, its function ceases long before the whole of the starch disappears. Its presence is necessary only until the leaves and roots are fully formed—when the plant is enabled to provide for itself, and becomes independent of the starch of the seed. When this period arrives, therefore, the production of diastase is no longer perceived.

This I have said is one of the purposes which appears to be served by diastase in the vegetable economy. That it is the only one we have no reason to believe. There may be others quite as interesting which we do not as yet understand. This is rendered more probable by the fact that the diastase contained in one pound of malted barley is capable of converting into sugar five pounds of starch.* (Liebig.) And though at the temperature at which the seed germinates, more of this substance may be necessary to transform the same weight of starch than is required in our hands, when aided by artificial heat,—yet as we never in the ordinary course of nature find any thing superfluous or going to waste, there is reason to believe that the diastase may be intended also to contribute directly to the nourishment and growth of the plant. As it contains nitrogen, it must be derived from the gluten or vegetable albumen of the seed; and as a young plant of wheat, when already many inches from the ground, contains no more nitrogen than was originally present in the seed itself (Boussingault), this diastase may only be the result of one of those transformations of which gluten† is susceptible, and by which it is rendered soluble, and capable of aiding in the production of those parts of the substance of the growing plant into which nitrogen enters as a necessary constituent.

It may not be uninstructive if we pause here for a moment and consider the beauty of the arrangements we have just been describing. In passing through a new and interesting country we do not hesitate, at times, to stop and gaze, and leisurely admire. We cannot otherwise fully realize and appreciate its beauty. So in the domains of science, we cannot be ever hurrying on—we must linger occasionally, not only that we may more carefully observe, but that we may meditate and feel.

You see how bountifully nature has provided in the seed for the nourishment of the young plant, how carefully the food is stored up for it, and in how imperishable a form—how safely covered also and protected from causes of decay! For hundreds of years the principle of life will lie dormant, and for as many the food will remain sound and undiminished till the time of awakening comes. Though buried deep in the earth, the seed defies the exertions of cold or rain, for the food it contains is unaffected by cold and absolutely insoluble in water. But no sooner

* It is the diastase in malt which dissolves the starch of the barley in the process of brewing, but as the diastase contained in malt is sufficient to dissolve so large a quantity of starch, it is obviously a waste of labour to malt the whole of the barley employed. One of malt to three of barley would probably be sufficient in most cases to obtain a wort containing the whole of the starch in solution. Advantage is taken of this property in the manufacture of the *white beer* of Louvain, and of other places in Flanders, and in Germany, where the light colour is secured by adding a large quantity of flour to a decoction of a small quantity of barley.

† That *diastase* is merely *transformed* gluten we cannot say, because the exact chemical constitution of diastase is as yet unknown.

is the sleeping germ recalled to life, by the access of air and warmth and duly tempered moisture, than a new agent is summoned to its aid, and the food is so changed as to be rendered capable of ministering to its early wants. The first movement of the nascent germ—(and how it moves, by what inherent or impartial force, who shall discover to us?)—is the signal for the appearance of this agent—diastase—of which, previous to germination, no trace could be discovered in the seed. At the root of the germ, where the vessels terminate in the farinaceous matter, exactly where it is wanted, this substance is to be found;—there, and there only, resolving and transforming the otherwise unavailable store of food, and preparing it for being conveyed either to the ascending sprout or to the descending root. And when the necessity for its presence ceases—when the green leaf becomes developed, and the root has fairly entered the soil—when the plant is fitted to seek food for itself—then this diastase disappears, it undergoes itself a new conversion, and is prepared in another form to contribute to the further increase of the plant.

How beautiful and provident are all these arrangements!—how plastic the various forms of organic matter in the hands of the All-Intelligent!—how nicely adjusted in time and place its diversified changes! What an apparently lavish expenditure of forethought and kind provision, in behalf even of the meanest plant that grows!

§ 9. *Vegetable Acids.—Acetic acid, Oxalic acid, Tartaric acid, Citric acid, Malic acid.*

Another class of compound substances remains to be shortly considered,—those, namely, which possess sour or acid properties, and which are known to be present in large quantity in many plants, and more especially in the greater number of unripe fruits. They do not, taken as a whole, form any large portion of the entire produce, either of the general vegetation of the globe or of those plants which are cultivated for food; yet the growth of fruit—as in the grape, orange, and apple countries—is sufficiently extensive, and the general interest in the cultivation of fruit trees sufficiently great, to require that the nature of the substances contained in fruits, and the peculiar changes by which they are formed, should be in some measure considered and explained.

I.—ACETIC ACID.

Acetic acid or vinegar is the most extensively diffused, and the most largely produced, of all the organic acids. It is formed during the germination of seeds, and it exists in the juices of many plants, but it is most abundantly evolved during the fermentation, whether natural or artificial, of nearly all vegetable substances. When pure it is a colourless liquid, having a well known agreeably acid taste. It may be boiled and distilled over without being decomposed. The vinegar of the shops is generally very much diluted, but it can be prepared of such a strength as to freeze and become solid at 45° F., and to blister the skin and produce a sore when applied to any part of the body. When mixed with water it readily dissolves lime, magnesia, alumina, &c., forming *salts* called *acetates*, which are all soluble in water, and may, therefore, be readily washed out of the soil or of compost heaps by heavy falls of rain.

When perfectly free from water, acetic acid consists of—

Carbon . . .	47·5	per cent.,	or 4 atoms
Hydrogen . .	5·8	"	or 3 "
Oxygen . . .	46·7	"	or 3 "
	100		

It is therefore represented by the formula $C_4 H_3 O_3$—in which, as in those given in the preceding sections for starch, sugar, &c., the numbers representing the atoms of hydrogen and oxygen are equal, and consequently these elements are in the proportion to form water. Hence, vinegar, like sugar, may be represented by carbon and water.

Let us consider for a moment the several processes by which this acid is usually formed.

1°. *By the distillation of wood.*—This a method by which wood vinegar—often called *pyroligneous acid*—is prepared in large quantity. Wood which has been dried in the air is put into an iron retort and distilled. The principal products are vinegar, water, and tarry matter. The decomposition is of a complicated description, but by comparing the constitution of woody fibre with that of vinegar, we can readily see the nature of the changes by which the latter is produced.

WOODY FIBRE is $= C_{12} H_8 O_8$
3 of VINEGAR are $= C_{12} H_9 O_9$

Difference $= H_1 O_1$; or the elements of one atom of water. One portion of the woody fibre, therefore, combines with the elements of an atom of water, obtained by the decomposition of another portion, and thus vinegar is produced.

2°. *Manufacture of Vinegar from Cane Sugar.*—It is a well known fact in domestic economy, that if cane sugar be dissolved in water, a little vinegar added to it, and the solution kept for a length of time at a moderate temperature, the whole will be converted into vinegar without any sensible fermentation. This process is frequently followed in the preparation of household vinegar, and was formerly adopted to some extent in our chemical manufactories. It will be recollected that we represented CANE SUGAR by $C_{12} H_{10} O_{10}$, while
3 of VINEGAR $= C_{12} H_9 O_9$

Difference $H_1 O_1$; or the elements of an atom of water, which cane sugar must *lose* in order to be converted into vinegar. Whether the change in this instance takes place by the direct conversion of cane sugar into vinegar, or whether the former is previously transformed into grape sugar, has not been satisfactorily determined.

3°. *Manufacture of Vinegar from Alcohol.*—In Germany, where common brandy is cheaper than vinegar, it is found profitable to manufacture this acid from weak spirit. For this purpose it is mixed with a little yeast, and then allowed to trickle over wood shavings moistened with vinegar, and contained in a cask, the sides of which are perforated with holes for the admission of a current of air. By this method oxygen is absorbed from the air, and in 24 hours the alcohol in the spirit is converted into vinegar and water.

The explanation of this process is also simple, alcohol being represented by $C_4 H_6 O_2$. Thus—

$$\left.\begin{array}{rr} \text{Alcohol} = & C_4 H_6 O_2 \\ 4 \text{ of Oxygen} = & O_4 \\ \hline \text{Sum} & C_4 H_6 O_6 \end{array}\right\} = \left\{\begin{array}{rr} \text{Vinegar} = & C_4 H_3 O_3 \\ 3 \text{ of Water} = & H_3 O_3 \\ \hline \text{Sum} = & C_4 H_6 O_6 \end{array}\right.$$

4°. *Production of Vinegar by fermentation.*—When vegetable matters are allowed to ferment, carbonic acid is given off and vinegar is formed. In such cases this acid is the result of a series of changes, during which that portion of the vegetable matter which has at length reached the state of vinegar has most probably passed through the several previous stages of grape, sugar, and alcohol. The carbonic acid, as has already been explained (p. 115), is given off during the fermentation of the grape sugar, and the consequent formation of alcohol.

To simple transformations, similar to those above described, we can trace the origin of the vinegar which is met with in the living juices of plants, and among the products of their decay.

II.—TARTARIC ACID.

The grape and the tamarind owe their sourness to a peculiar acid to which the name of *tartaric acid* has been given. It is also present, along with other acids, in the mulberry, in the berries of the sumach (*rhus coriarii*), and in the sorrels, and has been extracted from the roots of the couch-grass and the dandelion.

When new wine is decanted from the lees, and set aside in vats or casks, it gradually deposits a hard crust or *tartar* on the sides of the vessels. This substance is known in commerce by the name of argol, and when purified is familiar to you as the cream of tartar of the shops. It is a compound of tartaric acid with potash, and from it tartaric acid is extracted for use in medicine and in the arts. The principal use of the acid is in certain processes of the calico printers.

The pure acid is sold either in the form of a white powder or of transparent crystals, which are colourless, and have an agreeable acid taste. It dissolves readily in water, and causes a violent effervescence when mixed with a solution of the carbonate of potash or of soda. As it has no injurious action upon the system, it is extensively used in artificial soda powders and effervescing draughts. When added in sufficient quantity to a solution containing potash, it causes a white crystalline powder to fall, which is cream of tartar (or *bitartrate of potash*), and from lime water it throws down a white chalky precipitate of *tartrate of lime*. Both of these compounds are present in the grape.

When perfectly free from water this acid consists of—

Carbon . . .	= 36·81	or 4 atoms.
Hydrogen . .	= 3·00	or 2 atoms.
Oxygen . . .	= 60·19	or 5 atoms.
	100	

It is therefore represented by the formula $C_4 H_2 O_5$.

If we compare the numbers by which the atoms of hydrogen and oxygen in this acid are expressed, we see that these elements are not in the proportion to form water, and that this substance, therefore, cannot, like

so many of those we have hitherto had occasion to notice, be represented by carbon and the elements of water *alone*.

It may be represented by

$$\left.\begin{array}{lll} 4 \text{ of Carbon} & = & C_4 \\ 2 \text{ of Water} & = & H_2\ O_2 \\ \text{and } 3 \text{ of Oxygen} & = & O_3 \end{array}\right\} \text{ or, } 4C+2H+3O$$

$$\text{Tartaric Acid} = C_4\ H_2\ O_5$$

And, though this mode of representation does not truly exhibit the constitution of the acid, inasmuch as we have no reason to believe that it really contains water as such—yet it serves to show very clearly that in the living plant this acid cannot be formed *directly* from carbon and the elements of water, as starch and sugar may, but that it requires also *three atoms of oxygen in excess* to every five of carbon and two of water. We shall, in the following lecture, see how nicely the functions of the several parts of the plant are adjusted,—at one period to the formation of this acid, and at another to its conversion into sugar during the ripening of the fruit.

III.—CITRIC ACID, OR ACID OF LEMONS.

This acid gives their sourness to the lemon, the lime, the orange, the cranberry, the red whortleberry, the bird-cherry, and the fruits of the dog-rose and the woody night-shade. It is also found in some roots, as in those of the dahlia pinnata, and the asarum europæum (*asarrabacca*), and mixed with much malic acid, in the currant, cherry, gooseberry, raspberry, strawberry, common whortleberry, and the fruit of the hawthorn.

When extracted from the juice of the lemon or lime, and afterwards purified, it forms transparent colourless crystals, possessed of an agreeable acid taste; effervesces like tartaric acid with carbonate of soda, and like it, therefore, is much employed for effervescing draughts. With potash it forms a soluble salt, which is a *citrate of potash*, and from lime water it throws down a white, nearly insoluble, sediment of *citrate of lime*, which re-dissolves when the acid is added in excess. In combination with lime it exists in the tubers, and with potash in the roots, of the Jerusalem artichoke.

When free from water, citric acid consists of

Carbon	41·49	= 4 atoms.
Hydrogen . . .	3·43	= 2 atoms.
Oxygen	55·08	= 4 atoms.
	100	

and is therefore represented by $C_4\ H_2\ O_4$.

This formula differs from that assigned to the tartaric acid only in containing one atom of oxygen less, O_4 instead of O_5. In the citric acid, therefore, there are 2 atoms of oxygen in excess, above what is necessary to form water with the 2 of hydrogen it contains.

IV.—MALIC ACID.

The malic and oxalic acids are more extensively diffused in *living* plants than any other vegetable acids. If acetic acid be more largely

formed in nature, it is chiefly as a product of the decomposition of organic matter, when it has already ceased to exist in, or to form part of, a living plant.

Along with the citric acid, it has been already stated that the malic occurs in many fruits. It is found more abundantly, however, and is the chief cause of the sour taste, in the unripe apple, [hence its name *malic* acid,] the plum, the sloe, the elderberry, the barberry, the fruit of the mountain ash, and many others. It is associated with the tartaric acid in the grape and in the Agave americana.

This acid is not used in the arts or in medicine, and therefore is not usually sold in the shops. It is obtained most readily, in a pure state, from the berries of the mountain ash. It forms colourless crystals, which have an agreeable acid taste. It combines with potash, soda, lime, and magnesia, and forms *malates*, and, in combination with one or more of these bases, it usually occurs in the fruits and juices of plants. The *malate* of lime is soluble, while the citrate, as already stated, is nearly insoluble, in water. This malate exists in large quantity in the juice of the house-leek (*sempervivum tectorum*), in the Sedum telephium, the Arum maculatum, and many other juicy and fleshy-leaved plants.

When perfectly free from water, the malic acid has exactly the same chemical constitution as the citric, and is represented by the same formula $C_4 H_2 O_4$. These two acids, therefore, bear the same relation to each other as we have seen that starch, gum, and sugar do. They are what chemists call *isomeric*, or are *isomeric* bodies. We cannot transform them, however, the one into the other, by any known means, though there is every reason to believe that they may undergo such transformations in the interior of living plants. Hence probably one reason also why the malic and citric acids occur associated together in so many different fruits.

V.—OXALIC ACID.

This acid has already been treated of, and its properties and composition detailed, in a preceding lecture (Lecture III., p. 47). It forms colourless transparent crystals, having an agreeably acid taste, and it effervesces with the carbonates of potash and soda, but on account of its poisonous qualities, it is unsafe to administer it as a medicine. It occurs in combination with potash in the sorrels, in rhubarb, and in the juices of many lichens. Those lichens which incrust the sides of rocks and trees, not unfrequently contain half their weight of this acid in combination with lime. It can be formed artificially by the action of nitric acid on starch, sugar, gum, and many other organic substances.

When perfectly free from water, oxalic acid contains no hydrogen; but consists of—

Carbon . . .	33·75 = 2 atoms	
Oxygen . . .	66·25 = 3 "	
	100	

and it is represented by $C_2 O_3$. When heated with strong sulphuric acid, it is decomposed and resolved into gaseous carbonic acid (CO_2) and carbonic oxide (CO) in equal volumes. This change is easily understood since $CO_2 + CO = C_2 O_3$.

§ 10. *General observations on the substances of which plants chiefly consist.*

It may be useful here shortly to review the most important facts and conclusions which have been adverted to in the present lecture.

1°. The great bulk of plants consists of a series of substances capable of being represented by, and consequently of being formed in nature from, carbon and the elements of water only. Such are woody fibre, starch, gum, and the several varieties of sugar (p. 111).

2°. Yet the crude mass of wood, as it exists in a full-grown tree, containing various substances in its pores, cannot be represented by carbon and the elements of water *alone*. It appears always to contain a small excess of hydrogen, which is greater in some trees than in others. Thus in the chesnut and the lime, this excess is greater than in the pines, while in the latter it is greater than in the oak and the ash. [For a series of analyses of different kinds of wood by Peterson and Schödler, see Thomson's *Organic Chemistry*, p. 849.]

3°. These substances are, in many cases, mutually convertible even in our hands. They are probably, therefore, still more so in nature.

It is to be observed, however, that all the transformations we can as yet effect are in one direction only. We can produce the above compounds from each other in the order of lignin or starch, gum, cane sugar, grape sugar—that is, we can convert starch into gum, and gum into sugar, but we cannot reverse the process, so as to form cane from grape sugar, or starch from gum.

The only apparent exception to this statement with which we are at present acquainted, occurs in the case of starch. When this substance is dissolved in *cold* concentrated nitric acid, and then mixed largely with water, a substance [the *Xyloidin* of Braconnot] falls to the bottom, which is a compound of the nitric acid with woody fibre (C_{12} H_8 O_8.) [Pelouze, see Berzelius *Arsberättelse*, 1839, p. 416.] In this instance, if the above observation is correct, there appears to be an actual conversion of starch into woody fibre.

But what *we* are as yet unable to perform may, nevertheless, be easily and constantly effected in the living plant. Not only may what is starch in one part of the tree be transformed and conveyed to another part in the form of sugar,—but that which, in the form of sugar or gum, passes upwards or downwards with the circulating sap, may, by the instrumentality of the vital processes, be deposited in the stem in the form of wood, or in the ear in that of starch. Indeed we know that such actually does take place, and that we are still, therefore, very far from being able to imitate nature in her power of transforming even this one group of substances only.

4°. Among, or in connection with, the great masses of vegetable matter which consist mainly of the above substances, we have had occasion to notice a few which contain nitrogen as one of their constituents—and which, though forming only a small fraction of the products of vegetable growth, yet appear to exercise a most important influence in the general economy of animal as well as vegetable life. The functions performed by diastase in reference to vegetable growth, and to the transformations of organized vegetable substances, have already been in some measure illustrated,—we shall hereafter have an opportunity of considering more

fully the influence which gluten and vegetable albumen exercise over the general efficiency of the products of vegetation in the support of animal life, and over the changes which these products must undergo, before they can be converted into the substance of animal bodies. In a former lecture (Lecture IV., p. 66), I have had occasion to draw your attention to the comparatively small proportion in which nitrogen exists in the vegetable kingdom, and to show that it must nevertheless be considered as much a necessary and constituent element in their composition as the carbon itself; the very remarkable properties we have already discovered in the compounds above mentioned strongly confirm this fact, and illustrate in a striking manner the influence of apparently feeble and inadequate causes in producing important natural results.

5°. With the exception of acetic acid, which in constitution is closely related to sugar* and gum, all the acid substances to which it has been necessary to advert, contain an excess of oxygen above what is necessary to form water with the hydrogen they contain. Thus

VINEGAR	$= C_4 H_3 O_3$	contains no excess of oxygen.
TARTARIC ACID	$= C_4 H_2 O_5$ . .	3 of oxygen in excess.
MALIC ACID / CITRIC ACID	$= C_4 H_2 O_4$ . .	2
OXALIC ACID	$= C_2 O_3$ . .	3

It requires a little consideration to enable us to appreciate the true importance of these and other organic acids, in the vegetable economy. At first sight they appear to form a much smaller part of the general products of vegetation than is really the case. We must endeavour to conceive the quantity actually produced by a single tree loaded with thousands of lemons, oranges, or apples,—or again, how much is formed during the growth of a single comparatively small plant of garden rhubarb in spring, if we would obtain an adequate idea of the extent to which these acids are constantly formed in nature. On the other hand, we must recollect also that the greater portion of the acid of fruits disappears as they ripen, if we would understand the true nature of the interest which really attaches to the study of these substances, of the changes to which they are liable, and of the circumstances under which in nature these changes take place.

6°. I will venture here to draw your attention for a moment to the nature and extent of that remarkable power over matter, which the chemist, as above explained, appears to possess. Such a consideration will be of value not only in illustrating how far we really can now, or may hereafter, expect to be able to influence or control natural operations, [see Lecture II., p. 32,] but what is probably of more value still, exhibiting the true relation which man bears to the other parts of creation; and, in some measure, the true position he is intended to occupy among them.

1°. We have seen that the chemist can *transform* certain substances one into the other, in a known order; but that as yet he cannot reverse that order. Thus far his power over matter is at present limited; but this limit he may at some future period be able to overpass, and we

* It is identical in constitution with *caramel* (p. 114)—the uncrystallizable sugar of syrups. For

Vinegar. Caramel.
$(C_4 H_3 O_3 \times 3) = C_{12} H_9 O_9$.

know not how far. The discovery of a new agent, or of a new mode of treatment, may enable him to accomplish what he has not as yet the means or the skill to perform.

2°. He has it in his power to form, actually to produce, some of the organic or organized substances which occur in living plants. He can form gum, and grape sugar, in any quantity. *Thus far he can imitate and take the place of the living principle itself.*

Numerous other cases are known, in which he displays a similar power. By the action of nitric acid upon starch or sugar, [see Lecture III., p. 47,] he can form *oxalic acid*, which, as has already been shown, occurs very largely in the vegetable kingdom. By the action of heat upon citric acid, he can decompose it and produce an acid which is met with in the Wolfsbane (Aconitum napellus), and hence is called *aconitic acid.** Also by the action of sulphuric acid he can change *salicine* and *phlorizine*—substances extracted respectively from the bark of the willow and from that of the root of the apple tree—into a resinous matter and *grape sugar*. So, of the compounds which are found in the solids and fluids of animal bodies, there are some which he has also succeeded in forming by the aid of his chemical art.

Elated by such achievements, some chemists appear willing to hope that all nature is to be subjected to their dominion, and that they may hereafter be able to rival the living principle in all its operations. It is true that what we now know, and can accomplish, are but the beginnings of what we may fairly expect hereafter to effect. But it is of consequence to bear in mind the true position in which we now stand, and the true direction in which all we at present know seems to indicate that our future advances in knowledge, and in control over nature, are likely to proceed. And this leads me to observe—

3°. That our dominion is at present limited solely to transforming and decomposing. We can *transform* woody fibre into gum or sugar—*we cannot form either gum or sugar by the direct union of their elements.* We can *resolve* salicine by the acid of sulphuric acid into resin and grape sugar; but we cannot cause the elements of which they consist to unite together in our hands, so as to form any one of the three. We cannot even cause the resin and the sugar to re-unite and rebuild the salicine from which they were derived.

So we can by heat drive off the elements of water from the citric and cause the aconitic acid to appear; but we cannot persuade the unwilling compounds, when thus separated, to return to their former condition of citric acid; and, if we could, we should still be as far removed from the power of commanding or compelling the direct union of carbon, hydrogen, and oxygen, in such proportions, and in such a way, as to build up either of the two acids in question.

Again, we can actually form oxalic acid by the action of nitric acid

* These two acids differ from each other only by the elements of an atom of water. Thus

Citric Acid . .	=	$C_4\ H\ O_4$
Aconitic Acid .	=	$C_4\ H_1\ O_3$
Difference . .	=	$H_1\ O$ or HO, one of water.

It is easy to see, therefore, how, by the evolution of the elements of an atom of water, the one acid may be changed into the other. The scientific reader will excuse me (if on the grounds of simplicity alone) for representing, both here and in the text, the citric acid by $C\ H_2\ O_4$, instead of by $C_{12}\ H_5\ O_{11} + 3HO$, which Liebig and his pupils prefer.

upon starch, or wood, or sugar, or any other of a great variety of vegetable substances—but we cannot prepare it by the direct union of its elements. We can only as yet procure it from substances which have already been *organized*—which have been themselves produced by the agency of the living principle.

The same remarks apply with slight alteration to those substances of animal origin to which I have above alluded as being within the power of the chemist to produce at will. There is hardly an exception to the rule, that in producing *organic* substances, as they are called, the chemist must employ other organic substances which are as yet beyond his art—which, so far as we know, can only be formed under the direction of the living principle. Thus the sum of the chemist's power in imitating organic nature consists, at present, in his ability—

1°. To *transform* one substance found only in the organic kingdom into some other substances, produced more or less abundantly in the same kingdom of nature. This power he exercises when he converts starch into sugar, or fibrin into albumen or casein.

2°. To *resolve* a more complex or compound substance into two or more which are less so, and of which less complex substances some may be known to occur in vegetable or animal bodies.

3°. To decompose organic compounds by means of his chemical agents, and as the result of such decompositions to arrive at one or more compounds, such as are formed under the direction of the living principle.

In no one case can he form the substances of which animals and plants chiefly consist, out of those on which animals and plants chiefly live.

But this is the common and every-day result of the agency of the living principle. Is there as yet, then, any hope that the chemical laboratory shall supersede the vascular system of animals and plants; or that the skill of the chemist who guides the operations within it, shall ever rival that of the principle of life which presides over the chemical changes that take place in animal and vegetable bodies?

The true place, therefore, of human skill—the true prospects of chemical science—are pointed out by these considerations. No science has accumulated so many and such various treasures as chemistry has done during the last 20 years—none is at present so widely extending the bounds of our knowledge at this moment as the branch of organic chemistry—men may therefore be excused for entertaining more sanguine expectations from the progress of a favourite science than sober reasoning would warrant. Yet it is of importance, I think, and especially in a moral point of view, that amid all our ardour, we should entertain clear and just notions of the kind and extent of knowledge to which we are likely to attain, and—as knowledge in chemistry is really power over matter—to what extent this power is likely ever to be carried.

At present, if we judge from our actual knowledge, and not from our hopes—there is no prospect of our ever being able to imitate or rival living nature in actually compounding from their elements her numerous and varied productions. That we may clearly understand, and be able to explain many of her operations, and even to aid her in effecting them, is no way inconsistent with an inability to imitate her by the resources of art. This will, I trust, appear more distinctly in the subsequent lecture.

LECTURE VII.

Chemical changes by which the substances of which plants chiefly consist are formed from those on which they live.—Changes during germination—during the growth of the plant—during the ripening of fruit.—Autumnal changes.

HAVING thus considered the nature and chemical constitution of those substances which constitute by far the largest part of the solids and fluids of living vegetables, we are now prepared for the further question —*by what chemical changes these substances of which plants consist, are formed out of those on which they live?*

The growth of a plant from the germination of the seed in spring till the fall of the leaf in autumn, or the return of the succeeding spring-time, may in perennial plants be divided into four periods—during which they either live on different food, or expend their *main* strength in the production of different substances. These periods may be distinguished as follows:—

1°. The period of germination—from the sprouting of the seed to the formation of the perfect leaf and root.

2°. From the expansion of the first true leaves to the period of flowering.

3°. From the opening of the flower to the ripening of the fruit and seed.

4°. From the ripening of the seed or fruit, till the fall of the leaf and the subsequent return of spring. On the ripening of the fruit the functions of annual plants are in general discharged, and they die; but perennial plants have still important duties to perform in order to prepare them for the growth of the following spring.

The explanation of the chemical changes to which our attention is to be directed will be more clear, and perhaps more simple, if we consider them in relation to these several periods of growth.

§ 1. *Chemical changes which take place during germination and during the development of the first leaves and roots.*

The general nature of the chemical changes which take place during germination is simple and easy to be comprehended.

Let us first consider shortly the phenomena which have been observed to accompany germination, and the circumstances which are most favourable to its rapid and healthy progress.

1°. Before a seed will begin to sprout, it must be placed for a time in a sufficiently moist situation. We have already seen how numerous and important are the functions which water performs in reference to vegetable life (Lecture II., p. 36,) in every stage of a plant's growth. In the seed no circulation can take place—no motion among the particles of matter—until water has been largely imbibed; nor can the food be conveyed through the growing vessels, unless a constant supply of fluid be afforded to the seed and its infant roots.

2°. A certain degree of warmth—a slight elevation of temperature—is also favourable, and in most cases necessary, to germination.

The degree of warmth which is required in order that seeds may begin to grow, varies with the nature of the seed itself. In Northern Siberia and other icy countries, plants are observed to spring up at a temperature but slightly raised above the freezing point (32° F.,) but it is familiar to every practical agriculturist, that the seeds he yearly consigns to the soil require to be protected from the inclemency of the weather, and sprout most quickly when they are stimulated by the warmth of approaching spring, or by the heat of a summer's sun.

The same fact is familiarly shown in the malting of barley, where large heaps of grain are moistened in a warm atmosphere. When germination commences, the grain heats spontaneously, and the growth increases in rapidity as the heap of corn attains a higher temperature. It thus appears that some portion of that heat which the growth of the germ and radicles requires, is provided by natural processes in the grain itself; in some such way as, in the bodies of animals, a constant supply of heat is kept up by the vital processes—by which supply the cooling effect of the surrounding air is continually counteracted.

We have seen in the preceding lecture, that the transformations of which starch and gum are susceptible, take place with greater certainty and rapidity under the influence of an elevated temperature. It will presently appear that such transformations are also affected during germination; there is reason, therefore, to believe that the external warmth which is required in order that germination may begin, as well as the internal heat naturally developed as germination advances, are both employed in effecting these transformations. And, as the young sprout shoots more rapidly under the influence of a tropical sun, it is probable that those natural agencies in general, by which such chemical transformations are most rapidly promoted, are also those by which the progress of vegetation is in the greatest degree hastened and promoted.

3°. It has been observed that seeds refuse to germinate if they are entirely excluded from the air. Hence seeds which are buried beneath such a depth of soil that the atmospheric air cannot reach them, will remain long unchanged, evincing no signs of life—and yet, when turned up or brought near the surface, will speedily begin to sprout. Thus in trenching the land, or in digging deep ditches and drains, the farmer is often surprised to find the earth, thrown up from a depth of many feet, become covered with young plants, of species long extirpated from or but rarely seen in his cultivated fields.

4°. Yet light is, generally speaking, prejudicial to germination. Hence the necessity of *covering* the seed, when sown in our gardens and corn fields, and yet of not so far burying it that the air shall be excluded. In the usual method of sowing broad-cast, much of the grain, even after harrowing, remains uncovered; and the prejudicial influence of light in preventing the healthful germination of such seeds is no doubt one reason why, by the method of dibbling, fewer seeds are observed to fail, and an equal return of corn is obtained from a much smaller expenditure of seed.

The reason why light is prejudicial to germination, as well as why the presence of atmospheric air is necessary, will appear from the following observation :—

5°. When seeds are made to germinate in a limited portion of atmos-

pheric air, the bulk of the air undergoes no material alteration, but on examination its oxygen is found to have diminished, and carbonic acid to have taken its place. Therefore, *during germination, seeds absorb oxygen gas and give off carbonic acid.*

Hence it is easy to understand why the presence of air is necessary to germination, and why seeds refuse to sprout in hydrogen, nitrogen, or carbonic acid gases. *They cannot sprout unless oxygen be within their reach.*

We have seen also in a previous lecture that the leaves of plants in the sunshine give off oxygen gas and absorb carbonic acid,—while in the dark the reverse takes place. So it is with seeds which have begun to germinate. When exposed to the light they give off oxygen instead of carbonic acid, and thus the natural process is reversed. But it is necessary to the growth of the young germ, that oxygen should be absorbed, and carbonic acid given of—and as this can take place to the required extent only in the dark, the cause of the prejudicial action of light is sufficiently apparent as well as the propriety of covering the seed with a thin layer of soil.

6°. During germination, vinegar (acetic acid) and diastase are produced. That such is the case in regard to the latter substance, has been proved in the previous lecture, (p. 118.) That acetic acid is formed is shown by causing seeds to germinate in powdered chalk or carbonate of lime, when after a time *acetate of lime** may be washed out from the chalk (Braconnot) in which they have been made to grow. The acid contained in this acetate must have been formed in the seed, and afterwards excreted or thrown out into the soil.

7°. When the germ has shot out from the seed and attained to a sensible length, it is found to be possessed of a sweet taste. This taste is owing to the presence of *grape* sugar in the sap which has already begun to circulate through its vessels.

It has not been clearly ascertained whether the vinegar or the diastase is first produced when germination commences, but there seems little doubt that the grape sugar is formed subsequently to the appearance of both.

8°. The young shoot which rises upwards from the seed consists of a mass of vessels, which gradually increase in length, and after a short time expand into the first true leaves. The vessels of this first shoot do not consist of unmixed woody fibre. It is even said that *no true wood is formed till the first true leaves are developed.*—[Lindley's *Theory of Horticulture.*] The vessels of the young sprout, therefore, and of the early radicles, probably consist of the *cellular fibre* of Payen. They are unquestionably formed of a substance which is in a state of transition between starch or sugar and woody fibre, and which has a constitution analogous† to that of both.

Having thus glanced at the phenomena which attend upon germination, let us now consider the chemical changes by which these phenomena are accompanied.

1°. The seed absorbs oxygen and gives off carbonic acid. We have

* *Acetate of lime* is a compound of acetic acid (vinegar) and lime, and may be prepared by dissolving chalk in vinegar. It is very soluble in water.

† By *analogous* I mean which may be represented by carbon and water.

already seen that the starch of the seed (C_{12} H_{10} O_{10}) may be represented by carbon and water,—by 12C + 10HO. Now it appears that in contact with the oxygen of the atmosphere, a portion of the starch is actually separated into carbon and water, the carbon at the moment of separation uniting with the oxygen, and forming carbonic acid (CO_2). This acid is given off into the soil in the form of gas, and thence partially escapes into the air; but for what *immediate* purpose it is evolved, or how its formation is connected with the further development of the germ, has not hitherto been explained.

2°. The formation of acetic acid (vinegar) from the starch of the grain is also easy to comprehend. For, as we have already seen,

STARCH . . . $= C_{12}\ H_{10}\ O_{10}$
3 of VINEGAR . . $= C_{12}\ H_9\ O_9$

Difference $=$ $H_1\ O_1$; or the elements of an atom of water. Therefore, in this early stage of the growth of the germ a portion of the starch is deprived of the elements of an atom of water, and at the same time transformed into vinegar.

Why is this vinegar formed? It is almost as difficult to answer this question as to say why carbonic acid is evolved from the seed, though both undoubtedly serve wise and useful ends.

It has been explained in the preceding lecture how the action of dilute acids gradually changes starch into cane sugar, and the latter into grape sugar. While it remains in the sap of the sprouting seed, the vinegar may aid the diastase in transforming the insoluble starch into soluble food for the plant, and may be an instrument in securing the conversion of the *cane* sugar, which is the first formed, into *grape* sugar,—since cane sugar cannot long exist in the presence of an acid.

After the acetic acid is rejected by the plant, it may act as a solvent on the lime and other earthy matters contained in the soil. Liebig supposes the especial function of this acid—the reason why it is formed in the germ and excreted into the soil—to be, to dissolve the lime, &c., which the soil contains, and to return into the pores of the roots, bearing in solution the earthy substances which the plant requires for its healthy growth. This is by no means an unlikely function. It is only conjectural, however, and since the experiments of Braconnot have shown that *acetate of lime*, even in small quantity, may be injurious to vegetation, it becomes more doubtful how far the formation of this compound in the soil, and the subsequent conveyance of it into the circulation of the plant, can be regarded as the special purpose for which acetic acid is so generally produced during germination.

3°. The early sap of the young shoot is sweet; it contains grape sugar. This sugar is also derived from the starch of the seed. Being rendered soluble by the diastase formed at the base of the germ, the starch is gradually converted into grape sugar as it ascends. The relation between these two compounds has been already pointed out.

STARCH . . . . . $= C_{12}\ H_{10}\ O_{10}$
GRAPE SUGAR . . . . $= C_{12}\ H_{12}\ O_{12}$

Difference . . . . $=$ $H_2\ O_2$; or the elements of two atoms of water. The water which is imbibed by the seed

from the soil, forms an abundant source from which the whole of the starch, rendered soluble by the diastase, can be supplied with the elements of the two atoms of water which are necessary to its subsequent conversion into grape sugar

4°. The diastase is formed when the seed begins to sprout, at the expense of the gluten or vegetable albumen of the seed, but as its true constitution is not yet known, we cannot explain the exact chemical changes by which its production is effected.

5°. When the true leaf becomes expanded, true wood first appears in sensible quantity. By what action of the sun's rays upon the leaf the sugar already in solution in the sap is converted into woody fibre, we cannot explain. The conversion itself is *in appearance* simple enough, since

GRAPE SUGAR . . . $= C_{12} H_{12} O_{12}$, and
WOODY FIBRE . . . $= C_{12} H_8 O_8$

Difference . . . . $= H_4 O_4$; or the former must part with the elements of four atoms of water only, to be prepared for its change into the latter. But the true nature of the *molecular** change by which this transformation is brought about, as well as the causes which lead to it and the immediate instruments by which it is effected, are all still mysterious.

§ 2. *Of the chemical changes which take place from the formation of the true leaf to the expansion of the flower.*

When the true leaf is formed the plant has entered upon a new stage of its existence. Up to this time it is nourished almost solely by the food contained in the seed,—it henceforth derives its sustenance from the air and from the soil. The apparent mode of growth is the same, the stem shoots upwards, the roots descend, and they consist essentially of the same chemical substances, but they are no longer formed at the expense of the starch of the seed, and the chemical changes of which they are the result are entirely different.

1°. The leaf absorbs carbonic acid in the sunshine, and gives off oxygen in equal bulk.† It is in the light of the sun that plants increase in size—their growth, therefore, is intimately connected with this absorption of carbonic acid.

If carbonic acid be absorbed by the leaf and the whole of its oxygen given off again,‡ carbon alone is added to the plant by this function of the leaf. But it is added in the presence of the water of the sap, and thus is enabled by uniting with it to form, as *it may be directed*, or as may be necessary, any one of those numerous compounds which may

* All bodies are supposed to consist of particles or *molecules* of exceeding minuteness, and all chemical changes which take place in the same mass of matter are supposed to be owing to the different ways in which these particles arrange themselves. We may form a remote idea of the way in which different positions of the same particles may produce different substances, by considering how different figures in Mosaic may be produced by different arrangements of the same number of equal and similar fragments of various colours.

† Such is *sensibly* the result of experiment. How far this result can be considered as universally true, will be examined hereafter

‡ It will be recollected that carbonic acid contains its own bulk of oxygen gas: if, therefore, the leaf give off the same bulk of oxygen as it absorbs of carbonic acid, the result must be as stated in the text.

be represented by carbon and water, (p. 111,) and of which, as we have seen, the solid parts of plants are chiefly made up.

There are two ways in which we may suppose the oxygen given off by the leaf to be set free, and the starch, sugar, and gum, to be subsequently formed.

A. The action of light on the leaf of the plant may directly *decompose the carbonic acid* after it has been absorbed, and cause the oxyen to separate from the carbon, and escape into the air;—while at the same instant the carbon thus set free, may unite with the water of the sap in different proportions, so as to produce either sugar, gum, or starch. Suppose 12 atoms of carbonic acid ($12\ CO_2$) to be thus decomposed, and their carbon to unite with 10 of water (10 HO), we should have

from 12 of CARBONIC ACID . = C_{12}
which united to 10 of WATER . . . = $H_{10}\ O_{10}$

would give 1 of GUM or of CANE SUGAR = $C_{12}\ H_{10}\ O_{10}$
while 24 of oxygen would be given off, *the whole of which would have been derived from the carbonic acid* absorbed by the plant.

B. Or the action of the sun's rays may be directed, in the leaf, to the *decomposition, not of carbonic acid, but of the water* of the sap. The oxygen of the water may be separated from the hydrogen, while at the same instant the latter element (hydrogen) may unite with the carbonic acid to produce the sugar or starch. The result here is the same as before, but the mode in which it is brought about is very differently represented, and appears much more complicated. Thus, suppose 24 of water (24 HO) to be decomposed, and to give off their oxygen into the air, 24 of oxygen would be evolved as in the former case, the whole of *which would be derived from the decomposition of water*, while there would remain

24 of HYDROGEN . . = H_{24}
Let this act on 12 of CARBONIC ACID = $C_{12}\ O_{24}$

and we have as the result . . . . . $C_{12}\ H_{24}\ O_{24}$;

or $\underbrace{C_{12}\ H_{10}\ O_{10}}_{\text{Starch, \&c.}} + \underbrace{14\ HO}_{\text{Water.}}$.

According to this mode of representing the chemical changes, water is first decomposed and its oxygen evolved, then its hydrogen again combines with the carbon and oxygen of the carbonic acid, and forming two products—water and sugar or starch. This view is not only more complicated, but it supposes the same action of light to be—continually, at the same time, and in the same circumstances—both decomposing water and *re*-forming it from its elements. While, therefore, there can be no doubt, for other reasons not necessary to be stated in this place, that the light of the sun really does decompose water in the leaves of plants, and more in some than in others—yet it appears probable that the oxygen evolved by the leaf is derived in a great measure from the carbonic acid which is absorbed; and that the principal part of the solid substance of living vegetables, in so far at least as it is derived from the air, is produced by the union of the carbon of this acid with the elements of the water in the sap.*

* I ought not to pass unnoticed the opinion of Persoz (*Chemie Moleculaire*), that the starch, gum, &c., of plants are formed by the union of *carbonic oxide* (CO) with the neces-

We have seen reason to conclude (p. 63) that, while plants derive much of their sustenance from the air, they are also fed more or less abundantly by the soil in which they grow. From this soil they obtain through their roots the carbonic acid which is continually given off by the decaying vegetable matter it contains. This carbonic acid will ascend to the leaf, and will there undergo decomposition along with that which is absorbed by the leaf itself. At least we know of no function of the root or stem by which the carbonic acid derived from the soil can be decomposed and deprived of its oxygen before it reaches the leaf.

It is distinctly stated, indeed, by Sprengel, [see above, p. 92,] that when the roots of a plant are in the presence of carbonic acid, the oxygen given off by the leaf is greater in bulk than the carbonic acid absorbed. But there is one observation in connection with this point which it seems to me of importance to make. The leaves supply carbon to the plant only in the form of carbonic acid, and they give off a bulk of oxygen gas not exceeding that of the acid taken in, [see note, below.] But if the carbon derived from the soil be also absorbed in the form of carbonic acid, and if the oxygen contained in this portion of acid is also given off by the leaf—either the quantity drawn from the soil must be small, compared with that inhaled from the air, or the oxygen given off by the leaf must, in the ordinary course of vegetation, be sensibly greater than the bulk of the carbonic acid which it absorbs.

We are too little familiar with the chemical functions of the several parts of plants to be able to pronounce a decided opinion on this point; but it appears evident that one or other of the three following conditions must obtain:—

(*a*). Either in the general vegetation of the globe the bulk of the oxygen gas given off by the leaf during the day must always be considerably greater than that of the carbonic acid absorbed by it; or

(*b*). The root or stem must have the power of decomposing carbonic acid and of separating and setting free its oxygen; or

(*c*). The plant can derive no considerable portion of its carbon from the soil, in the form of carbonic acid.

If the experiments hitherto made by the vegetable physiologists be considered of so decisive a character as to warrant us in rejecting the two former conditions, the third becomes also untenable.

sary proportions of oxygen and hydrogen derived from the water of the sap. This opinion implies that, in the leaf, carbonic acid (CO_2) is decomposed into carbonic oxide and oxygen ($CO + O$), and that water likewise is decomposed,—the oxygen produced by both decompositions being given off either into the air by the leaves, or into the soil by the roots. The production of grape sugar, therefore, according to this hypothesis, would be thus represented:—

		There are retained,	and given off.
From 12 of Carbonic Acid	$= 12CO_2$	C_{12} O_{12}	O_{12}
From 12 of Water	$= 12HO$	H_{12}	O_{12}
		$C_{12}H_{12}O_{12}$ grape sugar	O_{24}

Of the 24 of oxygen thus given off, the opinion of Persoz is, that only one-half is evolved by the leaf,—and the principal fact on which his opinion rests is that observed by De Saussure, that plants of *Vinca minor* gave off by their leaves, in his experiments, only two-thirds of the oxygen contained in the carbonic acid they absorbed. This result has led Berzelius also to conjecture that the leaves of plants do not retain merely the carbon of the carbonic acid, but some compound of carbon with oxygen, containing much less of this element than the carbonic acid does (*Traité de Chemie*, V., p. 69). The principal objection to this view, however, is the quantity of oxygen it supposes to be rejected by the root. The experiments on which it is founded require confirmation and extension.

3°. Without dwelling at present on this point, the above considerations may be regarded as giving additional strength or probability to the conclusions we formerly arrived at (p. 63) from other premises—that the roots, besides carbonic acid, absorb certain other soluble organic compounds, which are always present in the soil in greater or less quantity, and that the plant appropriates and converts these into its own substance. Some of these organic compounds may readily, and by apparently simple changes, be transformed into the starch and woody fibre of the living vegetable. The illustration of this fact will be reserved until, in the second part of these lectures, I come to treat of the vegetable portion of soils, and of the chemical nature and constitution of the organic compounds of which it consists, or to which it is capable of giving rise.

4°. The chemical changes above explained (*a*), show how, from carbonic acid and the elements of water, substances possessed of the elementary constitution of sugar and gum may, by the natural processes of vegetable life, obtain the elements of which they consist, and in the requisite proportions. They throw no light, however, upon the mechanism by which these elements are constrained, as it were, to assume *first* the form of gum or sugar, or soluble starch, and *afterwards*, in another part of the plant, of insoluble starch and woody fibre.

It is known that the sap deposits starch and woody fibre in the stem, only in its descent from the leaf,—and it is, therefore, inferred that the action of light upon the sap, as it passes through the green parts, is necessary to dispose the elements to arrange themselves in the form of vascular fibre or lignin. And as, by the agency of nitric acid, starch appears to be convertible into woody fibre (p. 126), it is not unlikely that the soluble substances, containing nitrogen, which are present in the sap may—as diastase does upon starch—exercise an agency in transforming the soluble sugar, gum, &c., of the sap into the insoluble starch and woody fibre of the seed and the stem. We are here, however, upon uncertain ground, and I refrain from advancing any further conjectures.

Two great steps we have now made. We have seen how the germ lives and grows at the expense of the food stored up in the seed—and how, when it has obtained roots and leaves, the plant is enabled to extract from the air and from the soil such materials as, in kind and quantity, are fitted to build up its several parts during its future growth. That considerable obscurity still rests on the details of what takes place in the interior of the plant, does not detract from the value of what we have already been able to ascertain.

§ 3. *On the production of oxalic acid in the leaves and stems of plants.*

In the preceding section we have studied the origin of those substances only which form the chief bulk of the products of vegetation, and which are characterized by a chemical constitution of such a kind as enables them to be represented by carbon and water. But during the stage of vegetable growth we are now considering, other compounds totally different in their nature are also produced, and in some plants in sufficient quantity to be deserving of a separate consideration. Such is the case with oxalic acid.

The circumstances under which this acid occurs in nature have al-

ready been detailed. It is found in small quantities in many plants. The potash in forest trees is supposed to be in combination with oxalic acid, while in the lichens *oxalate of lime* serves a purpose similar to that performed by the woody fibre of the more perfect plant; it forms the skeleton by which the vegetable structure is supported, and through which its vascular system is diffused.

The production of this acid in the living plant is readily understood when its chemical constitution ($C_2 O_3$) is compared with that of carbonic acid (CO_2). For

$$\begin{array}{lll} 2 \text{ of Carbonic Acid} & = & C_2 O_4 \\ 1 \text{ of Oxalic Acid} & = & C_2 O_3 \\ \hline \text{Difference} \quad . \quad . \quad . & & O_1 \end{array}$$

That is to say, 2 of carbonic acid are transformed into 1 of oxalic acid by the loss of 1 equivalent of oxygen—or generally, *carbonic acid by the loss of one-fourth of its oxygen may be converted into oxalic acid.*

But the leaf absorbs carbonic acid and gives off oxygen. In the lichens, therefore, which contain so much oxalic acid, a large portion of the carbonic acid absorbed is, by the action of light, deprived of only one-fourth of its oxygen, and is thus changed into oxalic acid. The same is true to a smaller extent of the sorrel leaves and stems, which owe their sourness to the presence of oxalic acid—of the leaves and stems of rhubarb also—in a still smaller degree of the beech and other large trees, in which much potash, and probably also of marine plants, in which much soda is found to exist. It must be owing to the peculiar structure of the leaves of each genus or natural order of plants, that the same action of the same light decomposes the carbonic acid in different degrees—evolving in some a less proportion of its oxygen, and causing in such plants the formation of a larger quantity of oxalic acid.

The fact of the production of this oxalic acid, to a very considerable amount in many plants, is a further proof of the uncertainty of those experiments from which physiologists have concluded that the leaves of plants emit a bulk of oxygen sensibly equal to that of the carbonic acid absorbed.*

I have referred the production of more or less oxalic acid in different plants to the special structure of each, and this must be true, where, in the same circumstances, different results of this kind are observed to take place—as where sorrels and sweet clovers grow side by side. Yet the influence of light of different degrees of intensity on the same plant, is beautifully shown by the leaves of the *Sempervivum arboreum*, of the *Portulacaria afra*, and other plants *which are sour in the morning, tasteless*

* Were we permitted, in the absence of decisive experiments, to state as true what theoretical considerations plainly indicate, we should say—

1°. That plants containing much oxalic or other similar acids, and not deriving much carbonic acid from the soil, must give off from their leaves a bulk of oxygen *less* than that of the carbonic acid absorbed.

2°. That plants containing no sensible quantity of such acids, nor fed by carbonic acid from the soil, may evolve oxygen sensibly *equal* in bulk to the carbonic acid absorbed.

3°. That if little of these acids be present, and much carbonic acid be absorbed from the soil, the volume of oxygen given off by the green parts of the plant must be sensibly *greater* than that of the carbonic acid they absorb.

4°. That the leaves of the pines and other trees containing much turpentine—in which hydrogen is in excess—must at all times give off oxygen in *greater* bulk than the carbonic acid they absorb. They must decompose water as well as carbonic acid, and evolve the oxygen of both.

in the middle of the day, and bitter in the evening.—[Sprenge, *Chemie*, II., p. 321.] During the night the oxygen has accumulated in these plants and formed acids containing oxygen in excess (p. 127.) As the day advances this oxygen is given off; under the influence of light the acids are decomposed, and the sourness disappears.

In the juices of plants before the period of flowering, other acids are met with besides the oxalic acid, though in much smaller quantity. As the most important of these, however, occur more abundantly in fruits, we shall consider the theory of their formation in the following section.

§ 4. *Of the chemical changes which take place between the opening of the flower and the ripening of the fruit or seed.*

The opening of the flower is the first and most striking step taken by the plant towards the production of the seed by which its species is to be perpetuated. That at this period a new series of chemical changes commences in the plant is obvious from the following facts:—

1°. That the flower leaves absorb oxygen and emit carbonic acid both by day* and by night (p. 95.)

2°. That they also occasionally emit pure nitrogen gas.

3°. That the juice of the maple ceases to be sweet when the flowers are matured (Liebig,) and that, in the sugar cane and beet root, the sugar becomes less abundant when the plant has begun to blossom.

These facts sufficiently indicate the commencement of new changes in the interior of plants at this period of their growth. That such changes go on until the ripening of the seed is also evident from these further observations:—

1°. That the husk of the future seed, as in the corn-bearing grasses (wheat, oats, &c.,) is filled at first with a milky liquid, which becomes gradually sweeter and more dense, and finally consolidates into a mixture of starch and gluten, such as is presented by the flour of different species of corn.

2°. That the fruit in which the seeds of many plants is enveloped is at first tasteless, afterwards more or less sour, and finally sweet. In a few fruits only, as in the lime, the lemon, and the tamarind, does a sufficient quantity of acid remain to be sensible to the taste, when the seed has become perfectly ripe. The acid and cellular fibre both diminish while the sugar increases.

3°. That fruits, while green, act upon the air like the green leaves and twigs—but that, as they approach maturity, they also absorb or retain oxygen gas (De Saussure.) The same absorption of oxygen takes place when unripe fruits are plucked and left to ripen in the air (Berard.) After a time the latter also emit carbonic acid.

I.—FORMATION OF THE SEED.

In the case of wheat, barley, or other plants, which yield farinaceous seeds, we have seen that previous to flowering the chief energy of the living plant is expended in the production of the woody fibre of which its stem and growing branches mainly consist; and we have also been able to understand, in some degree, how this woody fibre is produced from the ordinary food of the plant. When the flower expands, how-

* By day the absorption is the greater, but the bulk of the oxygen taken in is always greater than that of the carbonic acid given off.

ever, the plant has in general, and especially if an annual plant, reached nearly to maturity, and woody fibre is little required. The most important of its remaining functions is the production of the starch and gluten of the seed, and of the substances which form the husk by which the seed is enveloped.

In the first stages of the plant's growth, the starch of the seed is transformed into gum and sugar, and subsequently, when the leaves are expanded, into woody fibre. In the last stages of its existence, when it is producing the seed, the sugar of the sweet and milky sap is gradually transformed into starch—that is to say, a process exactly the converse of the former takes place.

We are able, in some measure, to explain the mode and agency by which the former transformation is effected—the latter, however, is still inexplicable. We can ourselves, by the agency of diastase, transform starch into sugar; and, therefore, can readily believe such transformations to be effected in the young plant;—but we as yet know no method of *re*-converting sugar into starch; and, therefore, we can only hazard conjectures as to the way in which this change is brought about in the interior of the plant during the formation of the seed.

It is said that nitrogen is given off by the flower leaf. We know that this element is present in the colouring matter of the petal, and that it is a necessary constituent of the albumen and gluten, which are always associated with the starch of the seed. It is plain, then, that the nitrogeneous substances [substances containing nitrogen,] contained in the sap at all periods of the plant's growth, are carried up in great quantity to the flower and seed vessel. These substances are *supposed* to be concerned as immediate agents in effecting the transformations which there take place. More than this, however, we cannot as yet venture even to conjecture.

II.—RIPENING OF THE FRUIT.

In these plants, again, which invest their seed with a pulpy fruit—in the grape, the lemon, the apple, the plum, &c.—other changes take place, at this period, of a more intelligible kind, and other substances are formed, on the production of which less obscurity rests. At one stage of their growth, these fruits, as has been already stated, are tasteless—in the next, they are sour—in the third, they are more or less entirely sweet.

I. In the tasteless state they consist of little more than the substance of the leaf—of vascular, or woody fibre, filled with a tasteless sap, and tinged with the colouring matter of the green parts of the plant. For a time, this young fruit appears to perform in reference to the atmosphere the usual functions of the leaf—it absorbs carbonic acid and gives off oxygen, and thus extracts from the air a portion of the food by which its growth is promoted, and its size gradually increased.

II. But after a time this fruit becomes sour to the taste, and its acidity gradually increases—while at the same time it is observed to give off a less comparative bulk of oxygen than before. Let us consider shortly the theory of the production of the more abundant vegetable acids contained in fruits.

1°. The *tartaric acid* which occurs in the grape is represented by $C_4 H_2 O_5$ (p. 124).

There are two ways in which we may suppose this acid to be formed

in the fruit—either directly from the elements of carbonic acid and water with the *evolution* of oxygen gas—or from the gum and sugar already present in the sap aided by the *absorption* of oxygen from the atmosphere. Thus

A. 4 of CARBONIC ACID $= C_4 \quad O_8$
2 of WATER . . $= \quad H_2 O_2$

Sum . . $= C_4 H_2 O_{10}$ or $\overset{\text{Tartaric Acid.}}{C_4 H_2 O_5} + 5O$.

That is, one equivalent of tartaric acid may be formed from 4 of carbonic acid absorbed by the leaf or fruit, and 2 of the water of the sap, while 5 of oxygen are at the same time given off by the leaf. Or,

B. If Grape Sugar be $C_{12} H_{12} O_{12}$
$\frac{1}{3}$ of GRAPE SUGAR $= C_4 \quad H_3 \quad O_3$
3 of OXYGEN . . $= \quad O_3$

Sum . . $= C_4 \quad H_3 \quad O_6$ or $\overset{\text{Tartaric Acid.}}{C_4 H_2 O_5} + \overset{\text{Water.}}{HO}$.

That is, by the absorption from the air of a quantity of oxygen equal to that which it already contains, grape sugar may be converted into tartaric acid and water.

In the sorrels and other sour-leaved plants, which contain tartaric acid in their general sap, the acid may be formed by either of the processes above explained. In the sunshine their green parts absorb carbonic acid and evolve oxygen. If any of these green parts give off only $\frac{5}{8}$ of the oxygen contained in the carbonic acid they drink in, tartaric acid may be produced (A.) In the dark they absorb oxygen and give off carbonic acid. If the bulk of this latter gas which escapes be less than that of the oxygen which enters, a portion of the sugar or gum of the sap may, as above explained (B.), be converted into tartaric acid.

We have as yet no experiments which enable us to say by which of these modes the tartaric acid is really produced in such plants—or whether it may not occasionally be compounded by both methods.

In green fruits also, in the sour grape for example, it may, in like manner, be produced by either method. The only experiments we yet possess, those of De Saussure, though not sufficient to decide the point, are in favour of the former explanation (A.) In the estimation of this philosopher, the proportion of the oxygen of the carbonic acid which is retained by the fruit, is sufficient to account for the acidity it gradually acquires.

2°. *Malic and citric acids.*—These acids are represented (p. 127) by the common formulæ $C_4 H_2 O_4$. They may be produced from water and carbonic acid, if three-fourths only of the oxygen of the latter be given off. Thus

4 of CARBONIC ACID $= C_4 \quad O_8$
2 of WATER . . $= \quad H_2 O_2$

Sum . . $= C_4 H_2 O_{10} = \underbrace{\overset{\text{Malic Acid.}}{C_4 H_2 O_4}} + 6O$.

That such a retention of one-fourth of the oxygen of the carbonic acid occasionally takes place in the green fruit, is consistent with the observations of De Saussure. The lime and the lemon are fruits on which the most satisfactory experiments might be made with the view of finally determining this point.

III. This formation of acid proceeds for a certain time, the fruit becoming sourer and sourer; the acidity then begins to diminish, sugar is formed, and the fruit ripens. The acid rarely disappears entirely, even from the sweetest fruits, until they begin to decay; a considerable portion of it, however, must be converted into grape sugar, as the fruit approaches to maturity. This conversion may take place in either of two ways.

1°. By the direct evolution of the excess of oxygen. Thus

$$\begin{array}{lll} 3 \text{ of Tartaric Acid} & = & C_{12}\ H_3\ O_{15} \\ 6 \text{ of Water} \ldots & = & \quad H_6\ O_6 \\ \hline \text{Sum} \ldots & = & C_{12}\ H_{12}\ O_{21} = \underbrace{C_{12}\ H_{12}\ O_{12}}_{\text{Grape Sugar.}} + 9O. \end{array}$$

Or grape sugar may be formed from 3 of tartaric acid and 6 of the water of the sap, by the evolution, at the same time, of 9 of oxygen. Citric and malic acids, in the same proportion, would form grape sugar by the evolution of 6 of oxygen only.

Do fruits, when they have reached their sourest state, begin thus to give off an excess of oxygen? I know of no experiments which as yet decide the point.

2°. By the absorption of oxygen and the evolution of carbonic acid. Thus in the case of tartaric acid,

$$\begin{array}{lll} 1 \text{ of Tartaric Acid} & = & C_4\ H_2\ O_5 \\ 1 \text{ of Oxygen} \ldots & = & \quad O_1 \\ \hline \text{Sum} \ldots & = & C_4\ H_2\ O_6 = \underbrace{C_2\ H_2\ O_2}_{\text{½th of Grape Sugar.}} + \underbrace{2\ CO_2}_{\text{Carbonic Acid.}} \end{array}$$

Where one of oxygen is absorbed and two of carbonic acid given off. Or in the case of the malic and citric acids,

$$\begin{array}{lll} 1 \text{ of Malic Acid} & = & C_4\ H_2\ O_4 \\ 2 \text{ of Oxygen} \ldots & = & \quad O_2 \\ \hline \text{Sum} \ldots & = & C_4\ H_2\ O_6 = \underbrace{C_2\ H_2\ O_2}_{\text{½th of Grape Sugar.}} + \underbrace{2\ CO_2}_{\text{Carbonic Acid.}} \end{array}$$

Where 2 of oxygen are absorbed and 2 of carbonic acid given off.

We know from the experiments of Berard that, when unripe fruits are plucked, they do not ripen if excluded from the access of oxygen gas—but that in the air they ripen, absorbing oxygen at the same time, and giving off carbonic acid. This second method (2°) therefore exhibits the more probable theory of the ripening of fruits *after they are plucked*; and if—*as they become coloured*—fruits imitate the petals of the flower in absorbing oxygen from the air and giving off carbonic acid, it will also represent the changes which take place when they are permitted to ripen on the tree.

During the ripening of the fruit, it has been stated that the woody or cellular fibre it contains gradually diminishes, and is converted into sugar. This is familiarly noticed in some species of hard or winter pears. In sour fruit, the cellular fibre seldom exceeds 2½ per cent. of their whole weight;—in ripe fruits, however, it is still less, and as the constitution of this substance is so analogous to that of grape sugar, there is no difficulty in understanding that it may be readily converted into the latter, though the immediate agency by which the transformation is effected is as yet unknown to us.

§ 5. *Of the chemical changes which take place after the ripening of the fruit and seed.*

When the seed is fully ripe, the functions of annual plants are discharged. They no longer require to absorb and decompose carbonic acid, for their growth is at an end. Their leaves begin, therefore, to take in oxygen only, become yellow, and prepare along with the entire plant, for being finally resolved again into those more elementary substances from which they were originally compounded.

On trees and perennial plants, however, a further labour is imposed. In the ripened seed they have deposited a supply of food sufficient to sustain the germ that may spring from it, until it is able to seek food for itself; but the young buds already formed,—and which are to shoot out from the stem and branches in the ensuing spring,—are in reality so many young plants for which a store of food has yet to be laid up in the inner bark, and in the wood of the tree or shrub itself.

In the autumn, the sap of trees and permanent shrubs continues to flow rapidly till the leaf withers and falls, and the food of the plant is converted partly into woody fibre, as was the case during the earlier period of the year, and partly into starch. The former is deposited beneath the inner bark to form the new layer of wood by which the tree is annually enlarged; the latter—partly in the same locality, as in the birch and pine—partly throughout the substance of the wood itself, as in the willow—while in the palm trees and cycadeæ, it is intermingled with the central pith. The chemical changes by which the food is capable of being converted into these substances have already been considered. They proceed during the entire autumn, do not cease so long as the sap continues to move, and even in the depth of winter slowly and silently operate in storing up farinaceous matter—in readiness, like the starch in the seed, to minister to the nourishment of the young bud, when the warmth of the coming spring shall awaken it from its long sleep.

§ 6. *Of the rapidity with which these changes take place, and the circumstances by which they are promoted.*

But remarkable as those chemical changes are, the rapidity with which they sometimes take place is no less surprising.

From carbonic acid and water we have seen that the plant, by very intelligible processes, can extract the elements of which its most bulky parts consist—and can build them up in many varied ways, most of which are probably beyond the reach of imitation. But who can understand or explain the extraordinary activity which pervades the entire vascular system of the plant, when circumstances are favourable to its growth?

A stalk of wheat has been observed to shoot up three inches in as many days, of barley six inches in the same time, and a vine twig almost two feet, or eight inches a day (Du Hamel). Cucumbers have been known to acquire a length of twenty-four inches in six days, and in the Botanic Garden at Brussels I was shown a bamboo five inches in diameter, which had increased in height nine feet in twenty-seven days, sometimes making a progress of six to eight inches in a day. In our climate we meet with few illustrations of the rapidity with which plants are capable of springing up in the most favourable circumstances, and the above examples probably give us only an imperfect idea of the ve-

locity with which the bamboo, the palm, the tree fern, and other vascular plants, may grow in their native soil and climate. And with what numerous and complicated chemical changes is the production of every grain of the substance of these plants attended—how rapidly must the food be selected and absorbed from the air and from the soil—how quickly transformed and assimilated!

The long period of time during which, year after year, these changes may proceed in the same living vessels, or in the same tree, is no less wonderful. Oaks have lived to an age of 1500 or 2000 years—yew trees to 3000 years—and other species are mentioned as having flourished from 4500 to 6000 years; while even a living rose tree (*rosa canina*) is quoted by Sprengel as being already upwards of 1000 years old.—[Sprengel, *Lehre vom Dünger*, p. 76.]

The rapidity of the growth of a plant, and the length of its life, are equally affected by circumstances. On a knowledge of these circumstances, and of the means of controlling or of producing them, the enlightened practice of agriculture is almost entirely dependent.

Over the *natural* conditions on which vegetation in general depends, we can exercise little control. By hedge-rows and plantations we can shelter exposed lands, but, except in our conservatories and hot-houses, the plants we can expect to cultivate with profit will always be determined by the general climate in which we live. So the distribution of rain and sunshine are beyond our control, and though it is ascertained that a thundery condition of the atmosphere is remarkably favourable to vegetable growth, [Sprengel, *Lehre vom Dünger*, p. 73], we cannot hope that such a state of the air will ever be induced at the pleasure or by the agency of man. But under the same *natural* conditions of climate, there are many *artificial* methods by the use of which it is within our power to accelerate the growth, and to increase the produce, of the most valuable objects of ordinary culture.

Thus the germination of seeds in general is hastened by watering with a solution of chlorine (Davy), or of iodine or bromine (Blengini), and Davy found that radish seed which germinated in two days when watered with solutions of chlorine or sulphate of iron, required three when watered with very dilute nitric acid, and five with a weak solution of sulphuric acid.

It is familiarly known also in ordinary husbandry, that the application of manures hastens in a similar degree the development of all the parts of plants during every period of their growth—and largely increases the return of seed obtained from the cultivated grains. Ammonia and its compounds likewise, and nitric acid and its compounds, with many other saline substances existing in the mineral kingdom and occurring in soils, or which are produced largely in our manufactories, have been found to produce similar effects.

It would be out of place here to enter upon the important and interesting field opened up to us by a consideration of the influence exercised by these and other substances, in modifying both in kind and in degree the chemical changes which take place in living vegetables. The true mode of action of such substances—their precise effects—the circumstances under which these effects are most certainly produced—and the theoretical views on which they can be best accounted for—will form a subject of special and detailed examination in the third part of the present lectures.

LECTURE VIII.

How the supply of food for plants is kept up in the general vegetation of the globe.—Proportion of their food drawn by plants from the air.—Supply of carbonic acid.—Supply of ammonia and nitric acid.—Production of both in nature.—Theory of their action on living vegetables.—Concluding observations.

HAVING shown in the preceding Lecture in what way, and by what chemical changes, the substances of which plants chiefly consist may be produced from those on which they live,—there remains only one further subject of inquiry in connection with the organic constituents of plants.

Plants, as we have already seen, derive much of their sustenance from the carbonic acid of the atmosphere; yet of this gas the air contains only a very small fraction, and in so far as experiments have yet gone, this fractional quantity does not appear to diminish—how, then, is the supply of carbonic acid kept up?

Again, plants most probably obtain much of their nitrogen either from ammonia or from nitric acid; and yet, neither in the soil nor in the air do these compounds permanently exist in any notable quantity,—whence then is the supply of these substances brought within the reach of plants?

The importance of these two questions will appear more distinctly, if we endeavour to estimate how much of their carbon plants really draw from the atmosphere—and how much of the nitrogen they contain must be derived from sources not hitherto pointed out.

§ 1. *Of the proportion of their carbon which plants derive from the atmosphere.*

On this subject it is perhaps impossible to obtain perfectly accurate results. Several series of experiments, however, have been published, which enable us to arrive at very useful approximations in regard to the proportion of their carbon which plants, growing in a soil of ordinary fertility, and in such a climate as that of Great Britain, actually extract from the air by which they are surrounded.

1°. In an experiment made in 1824, upon common borage (Borago officinalis), Lampadius found that after a growth of five months (from the 3rd of April to the 6th of September) this plant produced ten times as much vegetable matter as the soil in which it grew had lost during the same period.* In other words, *it had drawn nine-tenths of its carbon from the air.*

2°. The experiments of Boussingault were made, if not with more care, at least upon a greater number of plants, and were protracted through a much longer period. It is necessary that we should understand the principle on which they were conducted, in order that we may be prepared to place confidence in the determinations at which he arrived.

* The above experiment may have been correctly made, but the result appears at first sight too startling to be readily received as indicative of the proportion of their sustenance drawn by plants from the air *in the general vegetation of the globe.*

If we were to examine the soil of a field on which we are about to raise a crop of corn—and should find it to contain a certain per-centage, say 10 per cent. of vegetable matter (or 5 per cent. of carbon);—and after the crop is raised and reaped should, on a second examination, find it to contain exactly the same quantity of carbon as before, we could not resist the conviction, that, with the exception of what was originally in the seed, the plant during its growth had drawn from the air all the carbon it contained. The soil *having lost none, the air must have yielded the whole supply.*

Or if after examining the soil of our field we mix with it a supply of farm-yard manure, containing a known weight, say one ton of carbon, and when the crop is reaped find as before that the per-centage of vegetable matter in the soil has suffered no diminution,* we are justified in concluding that the crop cannot, at the utmost, have derived from the soil any greater weight of its carbon than the ton contained in the manure which had been added to it.

Such was the principle on which Boussingault's experiments were conducted. He determined the per-centage of carbon in the soil before the experiment was begun—the weight added in the form of manure—the quantity contained in the series of crops raised during an entire rotation or course of cropping, until in the mode of culture adopted it was usual to add manure again—and lastly, the proportion of carbon remaining in the soil. By this method he obtained the following results in pounds per English acre, in three different courses of cropping, and on the same land:—

	Carbon in the manure.	Carbon in the crops.	Difference, or Carbon derived from the air.	Remarks.
First Course	2513	7544	5031	The first was a 5 years' course—of potatoes or red beet with manure, wheat, clover, wheat, oats; the second and most productive rotation was abandoned on account of the climate; the third was a 3 years' course.
Second do.	—	—	6839	
Third do.	—	—	3921	

The result of the first course indicates that—the land remaining in equal condition at the end of the four years as it was at the beginning—the crops collected during these years contained three times the quantity of carbon present in the manure, and *therefore the plants, during their growth, must on the whole have derived two-thirds of their carbon from the air.*

It will be shown in a subsequent section that even when the soil is lying naked the animal and vegetable matter it contains is continually undergoing diminution, owing to decomposition and the escape of volatile substances into the air. It is fair, therefore, to assume that a con-

* I need scarcely remark that, in the hands of a good farmer, who keeps his land in *good heart*—the quantity of organic matter in the soil at the *end* of his course of cropping should be as great, at least, as it was at the beginning of his rotation, before the addition of the manure.

siderable portion of the carbon of the manure and of the soil would naturally disappear during the four years' cropping above-mentioned, and that, therefore, the proportion of carbon derived from the air in Boussingault's experiments, must have been really considerably greater than is indicated by the numerical results.

Let two-thirds of the entire quantity of carbon contained in a series of crops be taken as the average proportion, [Lecture II., p. 31,] which, on cultivated land in our climate, must be derived from the air in the form of carbonic acid—and let the average weight of the dry crop reaped be estimated at a ton and a half per acre. Then, if the crop contain half its weight of carbon,* the plants grown on each acre must annually extract from the air 10 cwt. or 1120 lbs. of carbon in the form of carbonic acid.

§ 2. *Of the relation which the quantity of carbon extracted by plants from the air, bears to the whole quantity contained in the atmosphere.*

But the question will here at once suggest itself to you—does not the quantity thus extracted from the air really form a very large proportion of the whole weight of carbon which is contained in the atmosphere? A simple calculation will give us clear ideas in regard to this interesting point.

We have already seen that, by the results of De Saussure, the average quantity of carbonic acid in the atmosphere of our globe may be estimated at $\frac{1}{2500}$ part of its entire bulk. This is equal very nearly to $\frac{3}{5000}$ of its weight.† Or taking the whole weight of the atmosphere at 15 lbs. on the square inch—that of the carbonic acid will be 0·009 lbs. or 63 grs. per square inch. But as carbonic acid contains only 27⅔ per cent. of its weight of carbon, the weight of this element which presses on each square inch of the earth's surface is only 17⅔ (17·39) grs. Upon an acre this amounts to 7 tons.‡

But if the crop on each acre of cultivated land annually extracts from the air half a ton of carbon, the whole of the carbonic acid in the atmosphere would sustain such a vegetation over the entire globe for 14 years only. And if we even suppose such a vegetation to extend over one hundredth part of the earth's surface only, it still appears sufficient to exhaust the carbonic acid of the air in 1400 years.

* Boussingault states, that of all the plants usually cultivated for food—so far as his experiments have gone—the Jerusalem artichoke draws the largest portion of its sustenance from the air—or *yields the greatest weight of food from the smallest weight of manure.* It is true generally indeed that all those plants, which, like the Jerusalem artichoke and the white carrot, grow freely on sandy soils containing little vegetable matter and with the addition of little manure, extract the greatest proportion of their sustenance from the air. Such plants, therefore, are likely to prove the most profitable articles of culture where such soils and a scarcity of manure simultaneously prevail.

† The mean of 225 experiments made by De Saussure between 1827 and 1829 gave as above stated about 4–10000 or 1–2500th part for the mean bulk of the carbonic acid in the air, which is nearly 6–1000ths of its whole weight. Among these observations the maximum was 5·8 ten-thousandths, the minimum 3·15. If we take the maximum *bulk* at 6–10000ths of the air—the maximum *weight* of the carbonic acid is nearly 9–10000ths of that of the atmosphere. In elementary works it is generally stated in round numbers at 1–1000th of the weight of the air, but if the best experimental results we possess are to be any guide to us, this is at least one-third too high.

It is also of consequence to remark, that this estimate of the whole weight of the carbonic acid in the air is founded on the supposition that, in the highest regions of the atmosphere, the carbonic acid is present in a proportion nearly equal to that in which it is found immediately above the earth's surface—which is by no means established.

‡ 15·563 lbs.—an acre being 4840 square yards, containing each 1296 square inches.

A very short period, compared even with the limits of authentic history, has yet elapsed since experiments began to be made on the true constitution of the atmosphere; we have no very trustworthy data, therefore, on which to found a confident opinion in regard to the permanence of the proportion of carbonic acid which it now contains. The later observations of De Saussure do give a considerably lower estimate of the quantity of this acid in the air than that which was deduced from the results of the earlier experimenters; but the imperfection of the modes of analysis formerly adopted was too great, to justify us in reasoning rigorously from the inferences to which they led. We cannot safely conclude from them that the proportion of carbon in the atmosphere has really diminished to any sensible extent during this limited period; while the recorded identity of all the phenomena of vegetation renders it probable that the proportion has not sensibly diminished even within historic times.

From what sources, then, is the supply of carbonic acid in the atmosphere kept up?—and if the proportion be permanent, by what compensating processes is the quantity which is restored to the atmosphere produced and regulated?

§ 3. *How the supply of carbonic acid in the atmosphere is renewed and regulated.*

On comparing, in a previous lecture, the quantity of rain which falls with that of the watery vapour actually present in the air, we saw reason to believe that even in a single year the same portion of water may fall in rain or dew and ascend again in watery vapour several successive times. Is it so also with the carbon in the air? Does that which feeds the growing plant to-day, again mount up in the form of carbonic acid at some future time, ready to minister to the sustenance of new races, and to run again the same round of ever-varying change? Such is, indeed, the *general* history of the agency of the carbonic acid of the atmosphere; but when once it has been fixed in the plant it must pass through many successive changes before it is again set free. The conditions, also, under which it is restored to the atmosphere are so diversified, and the agencies by which, in each case, it is liberated, are so very distinct, as to require that the several modes by which the carbon of plants is reconverted into carbonic acid and returned to the air, should be made topics of separate consideration.

I.—ON THE PRODUCTION OF CARBONIC ACID BY RESPIRATION.

The air we breathe when it is drawn *into* the lungs, contains $\frac{1}{2500}$th of its bulk of carbonic acid; when it returns again *from* the lungs, the bulk of this gas amounts, on an average,* to $\frac{1}{25}$th of the whole; or *its quantity is increased one hundred times.*

The actual bulk of the carbonic acid emitted from the lungs of a single individual in 24 hours varies exceedingly; it has been estimated however, on an average, to contain upwards of five ounces of carbon.†

* It varies in different individuals from 2 to 8 per cent. of the expired air. In animals it varies also with the species. The air from the lungs of a cat contains from 5½ to 7 per cent., of a dog from 4½ to 6½, of a rabbit from 4 to 6, and of a pigeon from 3 to 4 per cent. of the whole bulk.—Dulong, *Annal. de Chim. et de Phys., third Series, I.*, p. 455.

† Davy, and Allen, and Pepys, estimated the weight of carbon evolved in a day at upwards of 11 ounces, a quantity which all writers have concurred in receiving with suspicion.

A full grown man, therefore, gives off from his lungs, in the course of a year, upwards of 100 lbs. of carbon in the form of carbonic acid.

If the quantity of carbon thus evolved from the lungs be in proportion to the weight of the animal, a cow or a horse ought to give off six times as much as a man.* From indirect experiments, however, Boussingault estimated the quantity of carbon actually lost in this way by a cow at 2200 grammes in 24 hours, and by a horse at 2400 grammes.—[*Ann. de Chim. et de Phys.*, lxxi., pp. 127 and 136.] These quantities are equal to 6 or 7 times the amount of carbon given off from the lungs of a man.

If we suppose each inhabitant of Great Britain, young and old, to expire only 80 lbs. of carbon in a year, the twenty millions would emit seven hundred thousand tons; and, allowing the cattle, sheep, and all other animals, to give off twice as much more, the whole weight of carbon returned to the air by respiration in this island would be about two millions of tons, or the quantity abstracted from the atmosphere by four millions of acres of cultivated land.

Whence is all this carbon derived? It is a portion of that which has been conveyed into the stomach in the form of food. Suppose the carbon contained in the daily food of a full grown man to amount to one pound—which is a large allowance—then it appears that, by the ordinary processes of respiration, *at least one-third of the carbon of his food is daily returned into the air.*

In other animals the proportion returned may be different from what it is in man, yet the life of all depends on the emission to a certain extent of the same gas.† And since all are sustained by the produce of the soil, it is obvious that the process of animal respiration is one of those methods by which it has been provided that a large portion of the vegetable productions of the globe should be almost immediately resolved into the simpler forms of matter from which it was originally compounded, and again sent up into the air to minister to the wants of new races.

II.—ON THE PRODUCTION OF CARBONIC ACID BY COMBUSTION.

Another important source of carbonic acid is familiar to us in the results of artificial combustion.

In the previous lecture I have shown how, by the action of the sun's rays upon the leaf, the carbonic acid absorbed from the atmosphere is deprived of its oxygen, and its carbon afterwards united to the elements of water for the production of woody fibre. During the process of combustion, this labour of the living leaf is undone—the carbon is made to combine anew with the oxygen of the atmosphere, and the vegetable matter is resolved again into carbonic acid and water.

Thus, when wood (woody fibre) is burned in the air, oxygen disappears, and carbonic acid and watery vapour are alone produced. The theory of this change is simple.

* Estimating the ordinary weight of a man at 150, and of a cow at 800 to 900 lbs.—See Sprengel, *Lehre vom Dünger*, p. 208.

* That the proportion *must* be less in the larger animals is certain, since the daily food of a cow may be stated generally as equivalent to 25 lbs. of hay, containing upwards of 10 lbs. of carbon. If one-third of this were given off from the lungs, the quantity of carbon (3⅓ lbs.) evolved would be ten times greater than was indicated by the experiments of Boussingault, and nearly double of what the weight of a cow, compared with that of a man, requires.

It will be recollected (p. 135) that in forming an equivalent of woody fibre or of sugar, 24 of oxygen were given off, chiefly by the leaf—so in again resolving these substances into carbonic acid and water, 24 of oxygen are absorbed. Thus—

1 of Woody Fibre	$= C_{12} H_8 O_8$		
24 of Oxygen . .	$= O_{24}$		
Sum . . .	$= C_{12} H_8 O_{32}$	$= 12CO_2$ (12 of Carbonic Acid.)	$+ 8HO$ (8 of Water.)
Or, 1 of Cane Sugar	$= C_{12} H_{10} O_{10}$		
24 of Oxygen . .	$= O_{24}$		
Sum . . .	$= C_{12} H_{10} O_{34}$	$= 12CO_2$ (12 of Carbonic Acid.)	$+ 10HO$ (10 of Water.)

The same law holds in regard to all other vegetable substances. They are resolved into carbonic acid and water, in proportions which necessarily vary with the chemical constitution of each.

It applies also to all bodies of vegetable *origin*, among which nearly all combustible minerals may be reckoned. The peat and coal we burn in our houses and manufactories, when supplied with a sufficiency of atmospheric air, are resolved during combustion into carbonic acid and watery vapour.

Some vegetable substances contain a small quantity of nitrogen. When these are burned, this nitrogen escapes into the atmosphere,—generally in an uncombined state,—and mingles with the air. So in animal substances, nearly all of which contain nitrogen as an essential constituent. During perfect combustion the whole of the carbon is dissipated in the form of carbonic acid, while the nitrogen rises along with it in an elementary state.

The result of this uniform subjection of all combustible matter to the operation of this one law, is the constant production on the surface of the globe of a vast quantity of carbonic acid;—the *re*-conversion of large masses of organic matter into the more elementary compounds from which it was originally formed.

How interesting it is to contemplate the relations, at once wise and beautiful, by which through the operation of such laws, dead organic matter, intelligent man, and living plants, are all bound together! The dead tree and the fossile coal lie almost useless things in reference to animal and vegetable life,—man employs them in a thousand ways as ministers to his wants, his comforts, or his dominion over nature—and in so doing, himself directly though unconsciously ministers to the wants of those vegetable races, which seem but to live and grow for his use and sustenance.

It is impossible to say what proportion of the carbon absorbed during the general vegetation of the globe, is thus annually restored to the atmosphere by the burning of vegetable matter. That it must be very great, will appear from the single fact, that by far the greater part of the globe is dependent for its supply of fuel on the annual produce of its forests;—while even in those more favoured countries where mineral coal abounds, the quantity of wood consumed by burning falls but little short of the entire yearly growth of the land.

In connection with this subject, I must draw your attention to one interesting, as well as important, fact. I have spoken of coal as a substance of vegetable origin, and there is no doubt that all the carbon it contains once floated in the air in the form of carbonic acid. But the period when it was so mixed with the atmosphere is remote almost beyond conception. When, therefore, we raise coal from its ancient bed and burn it on the earth's surface, *we add to the carbon of the air a portion which has not previously existed in the atmosphere of our time.*

The coal consumed in Great Britain alone is estimated at 20 millions of tons, containing on an average at least 70 per cent., or 14 millions of tons of carbon. But if the annual produce of an acre of cultivated land contain half a ton (p. 147) of carbon derived from the air, the coal consumed in this country would supply carbonic acid to the crops grown upon 28 millions of acres. Or, since in Great Britain about 34 millions of acres are in cultivation (p. 12), *the coal we annually consume produces a quantity of carbonic acid which is alone sufficient to supply food to the crops that grow upon seven-eighths of the arable land of this country.*

III.—PRODUCTION OF CARBONIC ACID BY THE NATURAL DECAY OF VEGETABLE MATTER. LAW OF THIS DECAY.

Over large tracts of country in every part of the globe, the vegetable productions of the soil are never cropped or gathered, but either accumulate—as occasionally in our peat bogs; or decay and gradually disappear—as in the jungles of India or in the tropical forests of Africa and Southern America.

The *final* results of this decay are the same as those which attend upon ordinary combustion, but the conditions under which it takes place being different, the *immediate* results are to a certain extent different also.

When a vegetable substance is burned in the air, the oxygen of the atmosphere is the only material agent in effecting the decomposition. The carbon of the burning body unites *directly* with this oxygen and forms carbonic acid.

In the natural process of decay, however, at the ordinary temperature of the atmosphere, vegetable matter is exposed to the action of both air and water; these both co-operate in inducing and carrying on the decomposition, and hence carbonic acid is not, as in the case of combustion, the chief or immediate result.

A detail of all the steps through which vegetable matter is known to pass before it is finally resolved into carbonic acid and water, would be difficult for you to understand, and is here unnecessary. A general view of the way in which by the united agency of air and water, the decay of organic substances is effected and promoted, may be made very intelligible, and will sufficiently illustrate the subject for our present purpose.

In combustion, as we have seen, the *whole* of the vegetable substance is resolved directly into carbonic acid and water, at the expense of the oxygen of the atmosphere. In natural decay a small and variable portion only is so changed, but to the extent to which this change does take place carbonic acid is directly formed and sent up into the air. Suppose such a change—a slow combustion in reality—to take place to a certain

extent, and let us consider what becomes of the remainder of the vegetable matter.

1°. If we add

6 of CARBONIC ACID . . $= C_6 \quad O_{12}$

to 6 of LIGHT CARBURETTED HYDROGEN (CH_2) $= C_6 \quad H_{12}$

we have the sum . . $= C_{12}\ H_{12}\ O_{12}$; or, one of grape sugar;—that is, one of grape sugar may be formed out of the elements of 6 of carbonic acid, and 6 of light carburetted hydrogen. Or, conversely, grape sugar being already produced, it may be resolved or decomposed into these two compounds in the same proportions, without the aid of the oxygen of the atmosphere.

2°. So if to

1 of WOODY FIBRE $= C_{12}\ H_8\ O_8$

we add 4 of WATER . . $= H_4\ O_4$

we have, as before, $C_{12}\ H_{12}\ O_{12} = \underbrace{6\,CO_2}_{\text{Carbonic Acid.}} + \underbrace{6\,CH_2}_{\text{Light Carburetted Hydrogen.}}$;

Or by the aid of the elements of 4 atoms of water, woody fibre may be resolved into 6 of carbonic acid and as many of light carburetted hydrogen.

3°. Again, in the case of a vegetable acid, if to

1 of TARTARIC ACID $= C_4\ H_2\ O_5$

we add 1 of OXYGEN . . $= O_1$

we have $C_4\ H_2\ O_6 = \underbrace{3\,CO_2}_{\text{Carbonic Acid.}} + \underbrace{CH_2}_{\text{Light Carburetted Hydrogen.}}$;

That is, by the aid of one of oxygen from the air, one of tartaric acid may be resolved into 3 of carbonic acid, and 1 of light carburetted hydrogen. It is easy to see how any other of the more common vegetable productions may—either at the expense of its own elements, as in grape sugar—or by the aid of those of water, as in woody fibre—or of the oxygen of the atmosphere, as in tartaric acid—be resolved into carbonic acid and light carburetted hydrogen, in certain proportions.

Now, such a resolution does really take place to a considerable extent in nature, during the decay of organic substances in moist situations. Hence the evolution of light carburetted hydrogen from dead vegetable matter in marshy places and stagnant pools—hence the production of the same gas in compost heaps, and especially in rich and heated farmyard manure—and hence also its occurrence in such vast quantities in many of our coal mines.

You will now be able to appreciate one of the reasons why this light carburetted hydrogen has been supposed by some physiologists (p. 50) to contribute as food to the ordinary nourishment of plants. It is produced in nature in many and varied situations, and it has been found by experiment to exercise a visible influence upon the growth of plants;—being so produced where young plants grow, is it never imbibed by them?—being possessed of this influence, is it entrusted with no control over the general vegetation of the globe?

However this may be, by far the greatest portion of both these gases escapes into the air;—the carbonic acid to fulfil those purposes which

have already been considered,—the light carburetted hydrogen to undergo a further change, by which it also is resolved into carbonic acid and water. Thus, if to

1 of LIGHT CARBURETTED HYDROGEN = CH_2 we add
4 of OXYGEN . . . . . = O_4

Carbonic Acid. Water.
We have $CH_2\ O_4$ or $CO_2 + 2HO$

Or one of this gas with 4 of oxygen may be changed into 1 of carbonic acid and 2 of water.

Now, when this gas escapes into the air it becomes diffused through a large excess of oxygen, and is thus ready, at any instant, to be decomposed. Through the atmosphere streams of electricity are continually flowing, and every wandering spark that passes athwart a portion of this mixture decomposes so much of the light gas, and produces in its stead the equivalent proportions of carbonic acid and watery vapour. Thus it happens that of the vast quantity of this and other combustible gases which are continually escaping into the air, so few traces are discernible even by the aid of the most refined processes of art. By a wise provision of nature such substances as are void of use to either animals or plants, if not speedily removed from the air altogether, are there converted into such new forms of matter as are fitted to minister to the necessities of living beings.

Though therefore in the natural decay of vegetable matter in the presence of air and moisture, a certain portion of its carbon escapes into the air in the form of light carburetted hydrogen, this compound is but a step towards the final change into carbonic acid and water. In the soil the vegetable matter is continually undergoing decay, various substances are produced in greater or less quantity, some solid, some liquid, and some gaseous like the light gas of which we have been speaking,—but all of them, like this gas, are only hastening—some by one road, so to speak, and some by another—towards that final destination which sooner or later they are all fated to reach; when in the form of carbonic acid and water they shall be in a condition to minister again to the nourishment of all plants.

While in the soil some part of this vegetable matter assumes forms which are capable of entering again into the roots of living plants, and, without further resolution in the air, of being converted by the living plant into portions of its own substance. The nature and composition of these forms of matter, so far as they are known, will be considered in a subsequent lecture.—[See Part II., Lectures XI.-XIII., "*On the constitution of soils.*"]

It is upon the *final* result of this natural decay to which all vegetable matter is subject, that the carbonic acid of the atmosphere depends for its largest supplies. The rapidity with which organized bodies perish, and become resolved into gaseous compounds, depends partly upon the climate and partly on the nature of the substances themselves,—but all hurry forward to the same end, and it is with difficulty that we are able for a time to arrest or even to retard their steps. It is by this perpetual and active obedience of all dead matter to one fixed law that the existing condition of things is maintained;—and thus it happens that either by the respiration of the animals which live upon it, by the process of

combustion, or by that of spontaneous decay, the entire crop of vegetable produce is *apparently*, year by year—taking the average of a series of years—resolved into the forms of matter from which it was originally built up;—and the substances on which plants feed at length restored to the air in the precise proportion in which they have been taken from it.

VI.—NATURAL EVOLUTION OF CARBONIC ACID IN VOLCANIC COUNTRIES.

The above *apparent* conclusion would be absolutely true, were there no causes in operation by which the restoration to the air of a portion of the carbon of animal and vegetable substances is prevented—and no other sources, independent of existing organic matter, from which carbonic acid may be supplied to the air.

If the whole of the carbon be not returned to the air, the carbonic acid of the atmosphere may be undergoing diminution; while—if a large supply be constantly poured into the air from sources independent of vegetable matter, the proportion of carbonic acid may be continually on the increase.

We have seen that the combustion of fossil coal adds to the air a large quantity of carbonic acid which has never before existed in the atmosphere of our time. In many volcanic districts also, carbonic acid is observed to issue in large quantity from cracks and fissures in the earth; —accompanied sometimes by water, forming mineral springs, from which the copious emisson of gas is readily perceived; more frequently, perhaps, rising up alone, and thus escaping general observation.

It must obviously be exceedingly difficult to estimate the quantity of gas which rises into the air in such circumstances over an extensive tract of country, fractured and broken up by volcanic agency—where the outlets are numerous, and the rate at which the gas escapes very variable. That in many localities it must be very great, however, there can be no question. In the ancient volcanic district of the Eifel, comprising an area of many square miles around the Laacher See, on the left bank of the Rhine, the annual evolution of carbonic acid from springs and fissures has been estimated by Bischof at not less than 100,000 tons, containing 27,000 tons of carbon. In many other districts, especially where active volcanoes exist, the volume of gas given off may be quite as great, though no attempts have hitherto been made to estimate its real amount.

Yet though absolutely large, the quantity of carbonic acid disengaged in this way from the earth, is really small when compared either with the entire quantity supposed to be present in the atmosphere, or with that which is required for the growth of the yearly vegetation of the globe. Suppose that from a thousand spots on the earth's surface a quantity of carbonic acid equal to the above estimate of Bischof escapes constantly into the air, the weight of carbon (27 millions of tons) thus diffused through the atmosphere would be only equal to that which is yearly drawn from the air by 54 millions of acres of land under cultivation (p. 147), and only twice as much as that contained in the coal which is annually consumed in Great Britain alone.

Still if the *whole* of the carbon contained in the produce of the general vegetation of the globe be ultimately restored to the air,—either by the respiration of animals, by the natural and slow decay of vegetable mat-

ter, or by the more rapid process of combustion,—the constant addition of carbonic acid derived from volcanoes, and from the combustion of fossil coal, should gradually, though slowly, augment the proportion of this gas in the air we breathe;—unless it be perpetually undergoing a permanent diminution, to at least an equal extent, from the operation of other causes. In reference to this point there are three circumstances which are proper to be considered:—

1°. It has been observed that, as we recede from the land and approach the centre of great lakes, or sail into the open sea, the quantity of carbonic acid in the air gradually diminishes. It is therefore inferred that the sea is constantly, and to a sensible extent, absorbing carbonic acid from the atmosphere, without afterwards restoring it, so far as is yet known, by any compensating process.

2°. The waters which flow into the sea or great lakes constantly bear down with them portions of animal and vegetable matter. These fall along with the mud which the waters hold in suspension, and are permanently imbedded in the deposits of clay, silt, and sand, which are continually in the course of formation.

3°. In many parts of the world, especially in the latitudes north and south of 45°, vegetable matter accumulates in the form of peat, becomes buried beneath clay and sand, and thus is prevented from undergoing the ordinary process of natural decay.

It is impossible to say how much carbon is permanently withdrawn from the atmosphere by these several agencies. There is reason to believe that it is quite as great as the quantity added to the air by the combustion of coal, and by the evolution of carbonic acid in volcanic districts. Indeed, the supply from these two sources appears to return only a small portion of that carbonic acid which is abstracted from the air by the agencies just stated, and which have been in operation during every geological epoch.

Conclusions.—The general conclusions, therefore, which we seem justified in drawing in regard to the supply of carbonic acid to the atmosphere are as follow:—

1°. That a large portion of the carbonic acid absorbed by plants is immediately and directly restored to the air by the respiration of the animals which feed upon vegetable productions.

2°. That a still larger portion is more slowly returned by the gradual re-conversion of vegetable substances into carbonic acid and water during the process of natural decay.

3°. That *nearly all* the remainder is given back in the results of ordinary combustion.

4°. That a further portion, which has not previously existed in the atmosphere of our time, is conveyed to it by the burning of fossil fuel, and by the emission of carbonic acid from cracks and fissures in the surface of the earth; yet that the quantity thus added cannot be supposed to exceed that which is constantly and *permanently* separated from the atmosphere by other causes.

The balance of all the evidence we possess is probably in favour of the opinion that the carbonic acid in the atmosphere is slowly diminish-

ing; we have, however, no satisfactory evidence either from theory or experiment that it has undergone any sensible diminution in our time.*

§ 4. *Of the supply of ammonia to plants.*

In a previous lecture it has been shown that in our cultivated fields plants derive a portion of their nitrogen from the manure which is added to the soil. But the quantity of this element present in the manure, supposing it all taken up and appropriated by the plant, is seldom equal to that contained in the series of crops which this manure assists in raising.

Thus, in the experiments of Boussingault already described (p. 144), the manure added previous to the first, or four years' course, contained 157 parts of nitrogen, while the crops contained 251 parts,—or *nearly two-thirds more than could be derived from the artificial manure.*

Whence is this excess of nitrogen derived, and in what form does it enter into the plant? Liebig replies to these questions, that the whole of the nitrogen absorbed by plants enters in the state of ammonia, and that the excess above what is present in the manure is drawn either from the soil or from the air. This opinion, advanced by so high an authority, demands our attentive consideration.

Ammonia has been detected in many clays, and traces of it may be discovered in most soils, but it is not known to be a natural or essential constituent of any of the solid rocks of which the crust of the globe is composed. These clays and soils, therefore, may be supposed to have derived their ammonia from the atmosphere; and Liebig ascribes the fertilizing action of the air upon stiff clays when fallowed, of burned clay when applied as a top-dressing, and of gypsum on grass lands [see note to page 53], to the larger quantity of ammonia which the surface of the soil is by these means caused to absorb and retain.

There is no question that ammonia is present in the atmosphere in small and variable quantity (p. 37). Whence is this ammonia derived, and is its quantity sufficient to supply the demands of the entire vegetation of the globe?

When animal substances undergo decay, nearly all the nitrogen they contain is ultimately separated from the other constituents in the form of ammonia. During the decay of plants also, a portion of their nitrogen escapes in the state of ammonia. Of the ammonia thus formed, much ascends into the air, chiefly in combination with carbonic acid as carbonate of ammonia (smelling salts), and much remains in the soil. Were the whole of the nitrogen contained in plants and animals to assume the form of ammonia when they decay, and to remain in the soil or in the air, it would always be within the reach either of the roots or leaves of the living races; and thus the same ammonia [or ammonia containing the same nitrogen—supposing the hydrogen to have been changed] might again and again return into the circulation of new vegetable tribes, and be always alone sufficient to supply all the demands of the existing vegetation of the globe.

But of the ammonia thus formed, a portion is daily washed from the soil by the rains and carried to the sea, and much more probably is

* In another work (*Chemical Geology*) now preparing for publication, I have discussed this question in connection with purely Geological considerations and without reference to *our time*; but it would be out of place to introduce here any train of reasoning which is not calculated to throw light on the phenomena of the existing vegetation of the globe.

washed from the air by the waters of the sea itself, or by the rains which fall directly into the wide oceans; and we know of no compensating process by which this ammonia can be restored to the air, and again made useful to vegetation.

Besides, of that which still remains in the air much must undergo decomposition by natural processes. In treating in a preceding section of the evolution of light carburetted hydrogen during the slow decay of vegetable matter (p. 153), I have shown how, in consequence of its admixture with the oxygen of the atmosphere, this gas is finely decomposed, while carbonic acid and water are produced. Ammonia in like manner will burn in oxygen gas, and when mixed with atmospheric air may be decomposed by the electric spark—water at the same time being formed and nitrogen set free. Thus,

if with 1 of AMMONIA $= NH_3$
we mix 3 of OXYGEN $= O_3$

we have the sum $NH_3\ O_3 = \underbrace{3\,HO}_{\text{3 of water.}} + \underbrace{N}_{\text{1 of nitrogen.}}$

or, when diffused through the air, 1 of ammonia, with the aid of 3 of oxygen, will yield 3 of watery vapour, while the nitrogen may* mingle with the air in an elementary form. Can we doubt that ammonia is thus decomposed in the air? Not to speak of other forms assumed by the electricity of the atmosphere, can the thunder-storms of the tropical regions pass unheeded the ammoniacal vapours they must meet with in their course?

I conclude, then, that of the ammonia which is formed from the nitrogen actually existing in animal and vegetable substances during their decay, only a *comparatively* small portion ever returns again to minister to the wants of new races.†

But if plants obtain all their nitrogen from ammonia,‡ how is this waste repaired—whence are new supplies constantly derived?

We have seen that, in certain volcanic countries, carbonic acid is evolved in vast quantities from rents and fissures in the earth. In some of these districts—and this has been observed more especially in Italy and Sicily, and it is said also to some extent in China—ammonia is likewise given off, in combination generally with some acid, and most frequently with the muriatic acid in the form of sal-ammoniac (muriate of ammonia). "*This ammonia,*" Liebig is correct in saying, "*has not been produced by the animal organism;*" but he assumes a very doubtful position when he adds, "*it existed before the creation of human beings; it is a part, a primary constituent of the globe itself.*"—[Organic Chemistry applied to Agriculture, p. 112.]

Where, we might ask, has this ammonia existed during all past time—from what deep caverns of the earth does it now escape?

* I say *may*, because it may at the same time combine with oxygen and form nitric acid.—See the following section, p. 239.

† I might add, that of the ammonia which does return, and is again absorbed, a portion is subsequently decomposed in the interior of living plants, as is shown by the evolution of nitrogen from the common leaves of some and the flower leaves of others.

‡ "Wild plants obtain *more nitrogen from the atmosphere, in the form of ammonia, than they require for their growth*, FOR the water which evaporates through their leaves and blossoms emits, after a time, a putrid smell—a peculiarity possessed only by such bodies as contain nitrogen."—[Liebig, *Organic Chemistry applied to Agriculture*, p. 95.] Does the fact here stated, justify the conclusion which appears to be drawn from it?

This opinion of Liebig, as well as the paramount influence he ascribes to ammonia over the vegetation of the globe, are based chiefly on the fact that we know of no means by which ammonia can be formed by the *direct* union of the hydrogen and nitrogen of which it consists.

But the production of ammonia, by the *indirect* union of these elements, is daily going on in nature, and can even be effected by different processes of art. Thus—

1°. When organic substances, which contain no nitrogen, are oxidized in the air, ammonia is not unfrequently formed (Berzelius). Hence it must be produced in unknown quantity during the annual decay of all vegetable substances.

2°. When organic substances are oxidized in the presence of air and water—as when moist iron filings are exposed to the air (Chevallier), or when certain oxidized substances are decomposed in the air by means of potassium (Faraday), or when metals, such as tin filings, are rapidly oxidized by means of nitric acid, ammonia is also produced in variable quantity. Hence the absorption of oxygen, even by the inorganic substances of the soil, may give rise to the formation of ammonia. But,

3°. The fact which most clearly illustrates the production of ammonia in nature, both on the surface of the earth, in the soil, and far in the interior near the seat of volcanic fires, is this, that if a currant of moist air be made to pass over red-hot charcoal, carbonic acid and ammonia are simultaneously formed.* This is in reality only a repetition in another form of what takes place, as above stated, when vegetable matter decays, or iron filings rust in moist air. The carbon and the iron decompose the watery vapour in the air, and combine with its oxygen, while, at the instant† of its liberation, the hydrogen of the water combines with the nitrogen of the air, and forms ammonia.

The source of the ammonia evolved in volcanic districts, therefore, is no longer obscure. The existence of combustible matter in such districts, and at great depths beneath the surface, can in few cases be doubted, and the passage of a mixed atmosphere of common air and steam over such combustible matter, at a high temperature, appears to be alone necessary to the production of ammonia. It is unnecessary, then, to have recourse to doubtful speculations in order to account for the natural reproduction of ammonia, to a certain extent, in the place

* This experiment is easily performed by *drawing* a current of mixed atmospheric air and steam through a red-hot gun-barrel filled with well-burned charcoal, and causing the current, on leaving the barrel, to pass through water acidulated with muriatic acid. After a time, the water, on evaporation, will be found to contain traces of sal-ammoniac. What thus takes place in a small experiment of this kind must more readily and more largely take place in the interior of the earth, where combustible substances at a high temperature happen to be exposed to a current of atmospheric air, mixed with watery vapour.

† A beautiful illustration of the tendency which elementary substances have to unite with each other at the *instant* of their liberation in what chemists call their *nascent* state, is mentioned by Runge.—*Einleitung in die technische Chemie*, p. 373.

If 1 part of hydrate of potash and 20 of iron filings be heated together, *hydrogen only is given off.*

If 1 of nitrate of potash and 20 of iron filings be heated together, *nitrogen only is given off.*

But if 40 of iron filings be mixed with 1 of hydrate and 1 of nitrate of potash, and then heated, *ammonia becomes perceptible.*

The nitrogen and hydrogen being given off together, at the same instant, some portions of each find themselves in a condition to unite, and thus ammonia is produced. The same result must follow in many natural operations, when hydrogen and nitrogen are set free from a previous state of combination, at the same time, and in the presence of one another.

of that which is constantly undergoing decomposition by the agency of causes such as those above described.

But is the indefinite quantity of ammonia reproduced by these indirect methods sufficient to replace *all* that is lost? Can it be supposed to impart to plants all the nitrogen they require? These questions will be considered in the following section.

§ 5. *Of the supply of nitric acid to plants.*

In regard to the action of nitric acid upon vegetation it is known—

1°. That when, in the form of nitrates of soda, potash, &c., it is spread upon the soil, it greatly promotes the growth and luxuriance of the crop and increases its produce; and

2°. That, when other circumstancs are favourable to vegetation—as in certain districts in India—the presence of an appreciable quantity of these nitrates adds largely to the fertility of the soil.*

The same effects are unquestionably produced by the addition of ammonia or by its natural presence in the soil. The beneficial influence of both compounds, then, being recognized, the relative extent to which each operates upon the general vegetation of the globe will be mainly determined by the circumstances and the quantity in which they respectively exist or are reproduced.

In regard to the existence of nitric acid, it is not known to form a necessary constituent of any of the solid rocks of which the crust of the globe is composed, but is diffused almost universally through the soil which overspreads the surface. In the hotter regions of the earth, in India, in Africa, and in South America (p. 56), it in many places accumulates in sufficient quantity to form incrustations of considerable thickness over very large areas, and in many more it can be separated by washing the soil. Even in the climates of Northern Europe, it is rarely absent from the water of artificial wells, into which the rains, after filtering through the surface, are permitted to make their way.†

On the whole, nitric acid and its compounds appear to *exist*, ready formed in nature, in larger quantity than either ammonia or any of its compounds.

* For the following, and other interesting notices, regarding Indian agriculture, I am indebted to Mr. Fleming, of Barochan, in Renfrewshire, whose long residence in the districts to which he alludes, as well as the interest he takes in practical agriculture, renders his testimony very valuable:

"The districts of Chaprah, Tirhoot, and Shahabad, near Patna, where a large proportion of the saltpetre sent from Bengal is produced, are considered the most fertile in Bengal, producing 2 and sometimes 3 crops yearly. The natives of these districts, particularly a caste called Quirees (hereditary gardeners), who cultivate the best land, and produce the best crops, are in the habit of irrigating their fields with water from wells so strongly impregnated with saltpètre and other salts as to be quite brackish, and they consider onions, turnips, and peas, most benefitted by this irrigation. Grain crops also grow most luxuriantly on lands yielding saltpetre, where there is enough of rain within a week or two after the seed is sown, but if a drought follows the sowing, and continues for 3 weeks or a month, the leaf becomes yellow, and the crop fails.

"The Hindoos do not generally manure their lands, as the dung of the cattle is used for fuel, but the Quirees collect the ashes of cow dung and of burned wood, and use it as a manure in some cases, chiefly for the poppy plant.

"The Hindoos have for ages been well acquainted with the rotation of crops, and the advantages of fallowing land, although a great proportion of the land is almost constantly in rice, Indian corn, or millet, during the rainy season, and in wheat or peas during the dry season."

† It occurs in the wells of the neighbourhood of Berlin (Mitscherlich), in the form of nitrates of potash, lime, and magnesia, in the wells around Stockholm, and may be expected in all wells that are dug (Berzelius).—*Traité de Chemie*, iv., p. 71.

Of these nitrates, as they do of ammonia, the rivers must be continually bearing a portion to the sea, but there are in nature unceasing processes of reproduction, by which not only this waste of the nitrates is repaired, but that further waste, also, which is caused by their absorption into the roots and subsequent decomposition in the interior of plants. Let us shortly consider these processes of reproduction.

1°. When a succession of electric sparks is passed through common air, nitric acid (NO_5) is slowly but sensibly formed. The currents of electricity which in nature traverse the atmosphere must produce the same effect, and the passage of each flash of lightning through the air must be attended by the formation of some portion of this acid.

After a thunder-storm plants appear wonderfully refreshed; in thundery weather they grow most luxuriantly, and other things being equal, those seasons in which there is much thunder are observed to be the most fruitful. Some have ascribed these results to the *immediate* agency of electricity on the growth of plants.—[Sprengel, *Chemie*, I., p. 99.] It is not equally possible that they may be connected with this necessary production of nitric acid?

In the rain which fell during 17 thunder-storms, Liebig found nitric acid always present and generally in combination with lime and ammonia. In the rain which fell on 60 other occasions, he could detect it only twice. In minute quantity nitric acid is difficult to detect. How much then must be formed in a thunder-storm, even in our climate, to make the presence of this acid *always* appreciable in the rain that falls —how vast a quantity in those warmer climates where such storms are so frequent and so appalling!

2°. When a mixture of ammonia with oxygen gas is exploded by passing an electric spark through it, a quantity of nitric acid is formed, even when the oxygen is not sufficient to oxidize the whole of the ammonia* (Bischof). Hence, if in the air, as we have seen reason to believe, the ammonia given off from decaying animal matters, and from other sources, be decomposed by the atmospheric electricity,—there will necessarily be formed at the same instant a portion of nitric acid, at the expense of the nitrogen of the ammonia itself. This nitric acid will, as necessarily, combine with some of the ammonia which still remains in the air. Hence the existence and production of *nitrate of ammonia* in the atmosphere, and the consequent presence of this acid along with ammonia in rain water.

Thus the very cause which in the preceding section was shown to operate in constantly diminishing the amount of ammonia in the air, and the operation of which certainly renders improbable the existence of this compound in the atmosphere in the large quantity supposed by some [see especially Liebig's *Organic Chemistry applied to Agriculture*, p. 74], this same cause is at the same moment constantly reproducing nitric acid. And, though much of what is thus produced must necessarily, as in the case of ammonia, be carried down to the sea by the rains, or be directly absorbed by the waters of the ocean themselves, yet

* It was shown above (p. 157), that 1 of ammonia (NH_3) requires 3 of oxygen to decompose it, forming 3 of water, and setting the nitrogen free. But, in reality, as Bischof has shown, the nitrogen is not wholly set free, but a portion both of its hydrogen and nitrogen combine with oxygen (are oxidized) at the same instant, forming simultaneously both water (HO), and nitric acid (NO_5).

it is obvious that in whatever proportion we may suppose the ammonia of the air to reach the leaves and roots of plants, in no less proportion must the nitric acid, with which it is associated, be enabled to enter into the circulating system of the various tribes of living vegetables, that flourish on every quarter of the globe.

3°. Again, we have seen that, during the decay of vegetable substances in moist air, ammonia is formed at the expense of the hydrogen of the water and of the nitrogen of the air. In consequence of, or in connection with, such decay, nitric acid is also largely produced in nature.

The most familiar, as well as the most instructive examples of this formation of nitric acid is in the artificial nitre beds of France and the north of Europe. These are formed by mixing earth of different kinds with stable manure or other animal and vegetable matters, and exposing the mixture to the air in long ridges or conical heaps, which are occasionally watered with liquid manure, and turned over, to expose fresh portions to the air. After a time, perhaps once a year, the whole is washed, when the water which comes off is found to contain a variable quantity of the nitrates of potash, soda, lime, and magnesia, which are employed for the manufacture of saltpetre. In these nitre beds it has been observed that the production of nitric acid either does not take place at all, or only with extreme slowness, unless animal and vegetable matter be present in considerable proportion. And yet the quantity of nitric acid which is formed is much greater than could be produced by the oxidation of the whole of the nitrogen contained in the organic matters present in the mixture.* It is also observed that the nitre beds are more productive when a portion from one outer face of the heap is lixiviated from time to time, and the washed earth added to the other side, than when the whole is lixiviated at once, and again formed into a heap and exposed to the air.

It appears, therefore, that organic matters are in our climate necessary to cause the formation of nitric acid to *commence*, but that after it has begun it will proceed in the same heap for an indefinite period, and at the expense apparently of the *nitrogen of the air only*.

Compost heaps are in general only artificial nitre beds, often unskilfully prepared and badly managed, producing, however, a certain quantity of nitrates, to the presence of which their effect on vegetation may not unfrequently be ascribed. To this fact we shall hereafter recur.

The soils in the plains of India, and in other similar spots in the tropical regions, may be regarded as *natural* nitre beds, in which, the decay of organic matter being vastly more rapid than in our temperate regions, the production of nitric acid is rapid in proportion.†

4°. But in many localities in which the presence of organic matter is

* Dumas, *Traité de Chemie*, II., p. 725. He adds, that 100 lbs. of nitre contain the nitrogen of 75 lbs. of ordinary animal matter, supposed in a dry state, or of 300 or 400 lbs. in its ordinary state of moisture,—a much greater relative proportion of animal matter than is ever added to the heap.

† We are as yet too little acquainted with the natural history of the district of Arica in South America, in which, as already stated (p. 56), the nitrate of soda has been accumulated in such large quantity, to be able to say to what *special* cause the accumulation is due. But as, from the description of Mr. Darwin, the locality appears to have been the site of an ancient lake, it is not unlikely that the nitrate may have been derived from the successive washings of a soil similar to that of India, by rains or periodical floods, which for a long period emptied themselves into or fed the lake.

not to be recognized in sensible quantity, the production of this acid is observed to proceed with a constant and steady pace. Thus, from the walls of certain caves in Ceylon a layer is yearly pared off, which yields an abundant crop of saltpetre (Dr. John Davy). The celebrated Mammoth cave in Kentucky, situated in a limestone ridge, yields an inexhaustible supply of nitrate of lime. During the war with Great Britain, fifty men were constantly employed in lixiviating the earth of this cave, and in about three years the washed earth is said to become as strongly impregnated as at first. Through the cave a strong current of air is continually rushing—inwards in winter, and outwards during the summer months. On the plaster of old walls, especially in damp situations, an efflorescence of this and other nitrates is frequently observed over every part of Europe. In China, according to Davis, the old plaster of the houses is so much esteemed as a manure, that parties will often purchase it at the expense of a coating of new plaster. Old clay walls, and especially the walls of clay-built huts, are said to be very fertilizing to the land, when applied as a top-dressing, and in some parts of England, where the land is poor, the people are said to pile up the soil in the form of walls, in order to improve its quality. These latter facts seem to indicate that both in China and England nitric acid is produced in similar circumstances, and that to its production the fertilizing action of the old plaster, and of the *weathered* clay, is alike to be attributed.

In the cultivated soil also, this acid is formed in ordinary circumstances. Braconnot found nitrate of potash in the botanic garden at Nancy, in a portion of soil in which poppies (*papaver somniferum*) had grown luxuriantly for ten years in succession—in larger quantity in the soil surrounding the interlaced roots of an *esclepias incarnata*, growing in an ordinary flower-pot, with a hole in the bottom—as well as in moss earth, in which a plant of *euphorbia breoni* had been grown in a pot.—[*Ann. de Chim. et de Phys.*, lxxii., p. 33 to 35.] There is little reason to doubt, indeed, that nitrates are to be found, in greater or less quantity, in all cultivated soils.

I shall not enter into a detailed inquiry how this nitric acid is formed. It is probable that as in the atmosphere ammonia may be decomposed and give rise to the formation of nitric acid, so in the soil this acid may result from a similar decomposition, proceeding more slowly, but according to the same natural laws. In warm climates, indeed, it appears certain that the ammonia which is evolved or formed during the decay of animal and vegetable substances, does speedily, and to a great extent, undergo oxidation,* and thus give rise to the greater abundance of nitric acid with which the tropical soils abound.

Thus, in the economy of nature, much ammonia is decomposed in the soil also, and hence another cause for the constant diminution of the quantity of this compound in addition to those already detailed in the preceding section.

But, besides the portion of this nitric acid, which owes its existence to

* For the perfect oxidation of 1 of ammonia, no less than 8 of oxygen are required. Thus

1 of Ammonia.		1 of Nitric Acid.	3 of Water.

$$NH_3 + 8O = NO_5 + 3HO.$$

the decomposition of ammonia, much, by far the greatest proportion in all probability, derives its origin from the union of the elements of the atmosphere itself. This direct union is effected in the *air*, as has been already shown, by the agency of atmospheric electricity; but it also takes place in the *soil* during the oxidation of the other elements contained in the organic matters which are there undergoing decay. The combination of the elements of ammonia in such circumstances proceeds on the principle that bodies, themselves undergoing oxidation, *dispose* other substances in contact with them (in this instance the nitrogen of the air) to unite with oxygen also. The presence of lime, potash, &c. in the soil, further induces to this oxidation by the tendency of these substances to combine with the acid which is formed by this union of the elements of which nitric acid consists.—It is impossible precisely to estimate the quantity of nitric acid produced in these various ways, through these various agents, and in these varied circumstances, or to balance it *accurately* against the amount of ammonia continually reproduced, as we have seen, in nature, wherever the necessary conditions present themselves. But, as I formerly concluded, that the amount of nitric acid actually existing in the superficial deposits of our globe is greater than that of ammonia, so I think that, in regard to the reproduction also of these two compounds, the balance is in favour of the former.

Since, then, nitric acid is fitted, by the solubility of its compounds, to enter into the circulation of plants in any quantity—since, when applied to them, it does undoubtedly promote, in a remarkable degree, the growth of plants—and since, in nature, it is continually reproduced in every country, and under such varied circumstances—I cannot withhold myself from the conclusion, that, over the general vegetation of the globe, it holds with ammonia at least an equal sway, and is appointed to exercise at least an equal influence over the growth of plants, both in their natural and in their cultivated state.

Still the influence of each is not unvaried by locality or by climate. The extent of dominion exercised by the nitrates probably diminishes as we recede from the equator, while that of ammonia increases,—it may be in an equal proportion. The reason of this probable variation will appear in the following section.

§ 6. *Theory of the action of nitric acid and ammonia.*

These two compounds act so far in common as to yield a supply of nitrogen to the plants into which they enter. They do so, however, under conditions which may be considerably different, and may be attended by unlike chemical changes.

I.—THEORY OF THE ACTION OF NITRIC ACID.

1°. The nitric acid of the nitrates entering into the circulation of the roots will ascend to the leaf, and will there be decomposed in the same way as the carbonic and other similar acids are, by the action of the sun's rays. It is only in the light of day that carbonic acid is decomposed in the green parts of plants—so must it be, generally, with the nitric acid which ascends to the leaf. Its oxygen will be given off, while its nitrogen may be retained in the circulating system of the plant. The extent to which this decomposition will take place at each passage

of the sap through the leaf will depend, in some degree, on the nature of the base (whether potash, soda, or lime,) with which the acid is in combination, but much more on the intensity of the light to which the green parts of the plant are exposed, and on the temperature of the air in which the plant happens to grow.

2°. It is still uncertain whether this acid is capable of being decomposed in the roots or stems of plants where it is excluded from the light, though it is very probable that it may be so, especially in cases where the juices naturally contain substances in which hydrogen is present in excess, or where such compounds make their way into the circulation of plants from the manure that may be applied to their roots.

Thus in the pines, in which turpentine (C_{40} H_{32}) naturally abounds, such a decomposition may the more readily occur, inasmuch as it would not necessarily imply the production and evolution of any gaseous substance. Thus

1 of OIL OF TURPENTINE, $= C_{40}\ H_{32}$ with the oxygen of
1 of NITRIC ACID (NO_5) $=$ O_5 gives

1 of RESIN, ... $= C_{40}\ H_{32}\ O_5$

By uniting with the oxygen of the nitric acid, therefore, oil of turpentine, in such trees, might be changed into resin during its passage through the stem, while the nitrogen, being set free, might, at the moment of its liberation, unite with other elements to form those parts or productions of the tree into which this element enters as a necessary constituent.

The above must be considered merely as an illustration of the *kind* of changes which may possibly take place in the interior of certain plants, and in the absence of light, when the nitrates happen to be present. Were I to affirm that such changes actually do occur in the presence of nitric acid, the theoretical chemist would have a right to expect that several collateral questions should be discussed, the consideration of which would here be out of place.

3°. The nitrates may also act in another way, which does not involve the necessity of the total decomposition of the acid they contain. We know that in nature many substances are capable of inducing chemical changes in other compound bodies, without themselves undergoing decomposition. Some beautiful illustrations of this have already been given in a previous lecture, when treating of the action of sulphuric acid upon starch and woody fibre, [Lecture VI., pp. 113, 114.] But the fact which most immediately bears on the influence of the nitric acid in the living plant, is that mentioned in p. 126,—that by solution in this acid in the cold, starch is converted into a substance having the composition of woody fibre. In the interior of the plant changes of this kind may be produced by simple contact only, with the nitric acid, so that, without being decomposed, it may be materially serviceable in promoting those molecular changes which are necessary to the healthy and rapid growth of the plant.

II.—THEORY OF THE ACTION OF AMMONIA.

1°. Ammonia is capable of contributing to the growth of the plant, by means of the hydrogen, as well as of the nitrogen it contains. We

have seen [notes to pages 136 and 138,] that, according to the results of the best experiments, the whole of the oxygen of the carbonic acid absorbed, is not given off by the leaves of all plants even in the sunshine,—while in the dark this gas is largely and directly imbibed from the air. If in the sap of a plant there be present at the same time a quantity of ammonia, the hydrogen of this ammonia may unite directly with the oxygen of the carbonic acid, forming water and a proportionate quantity of one or other of the several compounds (p. 112), which may be represented by carbon and water. Thus

3 of CARBONIC ACID, $= C_3 \quad O_6$ and the hydrogen of
2 of AMMONIA $(NH_3) = \quad H_6$

		½ of Grape Sugar.	3 of Water.
give	$C_3 H_6 O_6 =$	$C_3 H_3 O_3$	$+ 3HO$

so that where ammonia is present, and circumstances are favourable, sugar or starch may be formed in variable quantity, without the necessary evolution of oxygen gas. This change will take place in the interior of the leaf. And, if the direct decomposition of carbonic acid, and the evolution of its oxygen by the agency of the sun, take place at the same time—with a rapidity proportioned to the intensity of the light,—this simultaneous production of sugar, &c., from the presence of ammonia, must aid the increase and growth of the plant; and may be one main cause of the fertilizing action of this compound, which has been so long and so generally recognized.

When the hydrogen of the ammonia is thus worked up, the quantity of oxygen which escapes from the leaf must be less in proportion; and hence another cause (p. 138) for those discrepancies which have been observed in regard to the bulk of oxygen given off, compared with that of the carbonic acid taken in, by the leaves of different plants.

But at the same time the nitrogen is set free. This nitrogen will either be again compounded in the plant with other elements, or, if not required for its healthy growth—that is, if more largely present than is required by the plant—it will be directly emitted by the leaves, or sent downwards and permitted to escape by the root. Hence the reason why pure nitrogen is evolved from the leaves of some plants (p. 95), and why ammonia exercises a beneficial action upon vegetation, in cases where all the nitrogen it contains is neither retained nor required by the plant.

Does this decomposition necessarily require the agency of light? May it not take place in the absence of the sun?

I will mention one or two facts which seem to throw light upon this point.

1°. Plants grow in the dark. Though feeble and blanched, they increase largely in bulk; they must, therefore, have the power of assimilating their food to a certain extent, *independent of the sun's rays.*

2°. Several species of Poa, Plantago, Trifolium arvense, Cheiranthus, &c., become green in the perpetual darkness of mines (Humboldt).

3°. When a little hydrogen is mixed with the air, plants become greenish, even in the dark (Sennebier); and when exposed to the sun, the green becomes unusually intense in such a mixture (Ingenhouss).

The immediate and visible effect of an application of ammonia, or of soot, or of any top-dressing containing ammonia, is to render the green colour much more intense, and in the darkest weather. It is therefore probable, I think, that the hydrogen of the ammonia contributes to this immediate effect, and that the ammonia itself may be decomposed and its elements appropriated to the nourishment of the living vegetable, either by the unaided vital powers of the plant, or in the presence of a feeble light only. Like water, ammonia is *peculiarly* liable to decomposition, not always of that perfect kind which, *for the sake of simplicity,* I have endeavoured to explain in the present lecture, yet such as to render the elements of which it consists available to the general nourishment of the plant.

§ 7. *Comparative influence of nitric acid and of ammonia in different climates.*

It follows, from what is above stated, that the beneficial influence of ammonia upon vegetation will be readily perceived in all climates in which plants are found to flourish. Its effects will be greater and more rapid where the heat and light are more intense,—only because by these agents the functions of all life are stimulated.

Not so with the nitric acid in the nitrates. In the presence of organic compounds, that is, in the sap of the plant, it is less easily decomposed than ammonia. It requires the interference of more powerful agents—of a higher temperature, or of more brilliant light,—and thus its efficacy upon vegetation will be more dependent upon season and climate.

Now, we have seen that in tropical countries the nitrates are produced in the greatest abundance, and there the high temperature and the brilliant sun should render them most useful to vegetation. Such is well known to be the case, and it may be regarded as one of those bountiful adaptations with which all nature is full—that in these warmer regions, the ammonia produced in the soil is first converted into nitric acid, that it may *remain fixed*, and that this acid again is decomposed by the same agents (light and heat), when it enters the living plant, and is required to minister to its growth. On the other hand, it may no less be regarded as a wise provision, that in colder and more uncertain climates, where warm and brilliant summers are less to be depended upon, that compound of nitrogen (ammonia) should more abound, which is most easily decomposed in the living plant, which is fitted in comparative darkness to yield up its nitrogen, and by the hydrogen it contains, to compensate in some slight degree for the partial absence of the sun's rays.

From these views, therefore, we should draw this further practical conclusion—that in our climate, ammonia is sure to promote vegetation, and in every season, while the nitrates will produce their *maximum* effect, other things being equal, in such only as have abundant warmth and sunshine. Is this conclusion consistent with observation? Will it serve to explain any of the apparent failures which have occasionally been experienced in the employment of the nitrates?

§ 8. *Stimulating influence of these compounds.*

There remains one other point in regard to the effect of these two compounds upon vegetation, to which I would request your attention.

We have seen that the quantity of nitrogen contained in a crop raised by the aid of farm-yard manure, is very much greater than that which exists in the manure itself, and the views just exposed serve to indicate the sources from which the excess is derived. But suppose that upon two patches of ground, of equal quality, the one of which is manured and the other not, equal quantities of the same seed be sown, it is consistent with experience—that the crop reaped from the manured portion will not only contain more nitrogen than that reaped from the unmanured portion, but so much more as shall considerably exceed that contained in the manure itself. Thus suppose the crop raised from the unmanured land to contain 100 lbs. of nitrogen, and that the manure laid on the other portion contained 100 lbs. also, the crop which is reaped from this latter portion, in favourable seasons, will exceed, and probably very far exceed, 200 lbs. Hence the effect of the ammonia, &c., in the farm-yard manure, is not merely to yield its own nitrogen to the plant, but to enable it, in some way hitherto unexplained, to draw from other sources a larger portion of the same element than it would otherwise do.

So also with the nitrates. If two equal portions of the same grass or corn-field, in early spring, be measured off, and one of them be top-dressed with nitrate of soda or with saltpetre, the weight of nitrogen contained in the crop of hay or corn reaped from the latter, will generally be found to exceed that contained in the crop from the former, by a quantity much greater than that which was present in the nitrate with which the land was dressed.* In addition, therefore, to the nitrogen di-

* The following calculations illustrate the statement in the text:—Mr. Gray, of Dilston, [see Journal of Royal English Agricultural Society,] applied nitrate of soda to grass land in the proportion of 112 lbs. to the acre.

The produce without nitrate amounted to 2 tons 81 stones
with 112 lbs. of nitrate to 3 tons 146 stones

Increase, 1 ton 65 stones, or 3150 lbs.

And 3150 ÷ 112 = 28½ lbs. the increase of hay from each pound of nitrate of soda.[1] But allowing this hay to contain only one per cent. of nitrogen, 28 lbs. will contain 4½ ounces of nitrogen, which is nearly double the quantity actually present in the nitrate employed.

Again, in the case of a crop of grain—Mr. Hyett applied nitrate of soda to a field of wheat, and compared the produce with that from an equal portion to which no top-dressing was applied.

	CORN.			STRAW.		
	Bush.	pks.	pts.	Cwt.	qrs.	lbs.
Nitrated	42	2	11	31	2	3
Without nitrate . .	33	2	6	23	1	21
Excess,	10	0	5	8	0	10

Calculating the bushel of corn at 60 lbs., the excess of corn amounted to 600 lbs., containing 24½ per cent. or 147 lbs. of gluten and albumen. The nitrogen in these substances, when properly dried, is from 15 to 17 per cent. If we suppose the gluten not to have been quite dry, and allow only 14 per cent. of nitrogen, 147 lbs. would contain 20½ lbs. of this element.

But the nitrated corn contained 5 per cent. more gluten and albumen than the un-nitrated, which in 33 bushels (2000 lbs.) gives 100 lbs. of gluten in excess, containing 14 lbs. of nitrogen.

And 8 cwt. of straw (900 lbs.) contained one-third of a per cent. of nitrogen, [Boussingault,] or in all 3 lbs.

Therefore the quantity of nitrogen present in the nitrated crop above that in the un-nitrated was as follows:

1°. In 600 lbs. of wheat at 24½ per cent. of gluten . . . . . 20½ lbs. Nitrogen.
2°. In 2000 lbs. of wheat at 5 per cent. of gluten contained in excess, 14 lbs. do.
3°. In 900 lbs. of straw at one-third per cent. . . . . 3 lbs. do.

Total nitrogen . . . . . = 37½ lbs.

But the nitrogen in 1 cwt. of dry nitrate of soda, as already stated, is only 19 lbs. or little

[1 Dry nitrate of soda contains about 16½ per cent. of nitrogen, being 19 lbs. to the cwt., or two and three-fifth ounces to the pound; but as it is usually applied, it contains from 5 to 10 per cent. of water. The nitrogen, therefore, may be estimated at 2½ ounces in the pound.]

rectly conveyed to the plant by these nitrates, they also exercise some other influence, by which they enable the living vegetable to draw from natural sources a much larger supply than they would otherwise be capable of doing. What is this influence, and how is it explained?

This I suppose to be that kind of influence to which writers on agriculture are in the habit of alluding, when they speak of certain substances *stimulating* plants, or acting as *stimulants* to their growth, though the term itself conveys to the mind no distinct idea of the mode of operation intended to be indicated—of the way in which the effect is produced.

In the present case, this special action of ammonia and the nitrates, and perhaps also of immediate applications of manure in general, appears to arise from their affording to the plant, in its early youth, a copious supply of nitrogenous food, by which it is enabled at once to shoot out in a more healthy and vigorous manner. It thrusts forth roots in greater numbers, and to greater distances, and is thus enabled to extract nourishment from a greater extent and depth of soil than is ever reached by the sickly plant—it expands larger and more numerous leaves, and thus can extract from the air more of every thing it contains which is fitted to supply the wants of the living vegetable; as the stout and healthy savage can hunt and fish to support many lives, while the feeble or sickly can scarcely secure sustenance for himself alone. Feed a wild animal well the first few months of its life, and you may set it loose to prey for itself; starve it in its infancy, and its growth and strength will be stunted, and it may lead a wretched and hungry life.

Even in soils, then, and situations, which are capable of yielding to the plant every thing it may require for its ordinary growth, it is an important object of the art of husbandry to discover what substances are especially *necessary* or grateful to particular crops, and to apply *these directly, and in abundance*, to the new-born plant,—in order that it may acquire sufficient strength to be able to avail itself in the greatest degree of the stores of food which lie within its reach.

Concluding observations regarding the organic constituents of plants.

We have now considered the most important of those questions connected with the organic elements of plants, which are directly interesting to the practical agriculturist. We have seen—

1°. That all vegetable productions consist of two parts—one the organic part, which is capable of being burned away in the air—the other, the inorganic part, which remains behind in the form of ash.

2°. That this organic part consists of carbon, hydrogen, oxygen, and nitrogen only.

3°. That plants derive the greater part of their carbon from carbonic acid, of their hydrogen and oxygen from water, and of their nitrogen from ammonia and nitric acid.

4°. That by far the largest portion of those substances which form the principal mass of plants, such as starch and woody fibre, consists of carbon united to oxygen and hydrogen in the proportions in which they

more than half the quantity, which in consequence of the presence and action of the nitrate the wheat was enabled to obtain and appropriate above the quantity appropriated by the wheat in the un-nitrated part of the field.

It requires no further proof, therefore, to show that *the nitrate of soda and the nitrates must act in some other way in reference to vegetation, than by simply supplying a portion of nitrogen.*

exist in water,—or, in other words, may be represented by carbon and water in various proportions.

5°. That the food on which they live enters by the roots and leaves of plants,—that the leaves, under the influence of the sun, decompose the carbonic acid, give off its oxygen, and retain its carbon,—and that this carbon, uniting with the elements of water in the sap, forms those several compounds of which plants chiefly consist.

6°. That the supply of carbonic acid in the atmosphere is kept up partly by the respiration of animals, partly by the natural decay of dead vegetable matter, and partly by combustion. That ammonia is supplied to plants chiefly by the natural decay of animal and vegetable substances—and nitric acid partly by the natural oxidation of dead organic matter, and partly by the direct union of oxygen and nitrogen, through the agency of the atmospheric electricity.

7°. That while both of these compounds yield nitrogen to plants, they each exhibit a special action on vegetable life, in virtue of the hydrogen and oxygen they respectively contain—and exercise also a so-called *stimulating* power, by which plants are induced or enabled to appropriate to themselves, from other natural sources, a larger portion of all their constituent elements than they could otherwise obtain or assimilate.

In illustrating these several points, it has been necessary to enter occasionally into details which, to those who have heard or may read only the later lectures, may not be altogether intelligible. I am not aware, however, of having introduced any thing of which the full sense will not appear on a reference to the statement by which it is preceded.

We are now to consider the *inorganic* constituents of plants,—their nature,—the source (the soil) from which they are derived,—their uses in the vegetable and animal economy,—how the supply of these substances is kept up in nature,—and how, in practical husbandry, the want of them may be at once *efficaciously and economically supplied by art.* This division of our subject, though requiring a previous knowledge of the principles discussed in the foregoing lectures, will be more essentially of a practical nature, and will lead us to consider and illustrate the great leading principle by which the practical agriculturist ought to be guided in the cultivation and improvement of his land.

We shall here also find much light thrown upon our path by the results of geological inquiry; and it is in the considerations I am now about to bring before you, that I shall have to direct your attention most especially to the principal applications of Geology to Agriculture.

LECTURES

ON THE

APPLICATIONS OF CHEMISTRY AND GEOLOGY

TO

AGRICULTURE.

Part XX.

ON THE INORGANIC ELEMENTS OF PLANTS.

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LECTURE IX.

Inorganic constituents of vegetable substances.—Relative proportions of organic and inorganic matter in plants.—Unlike proportions in unlike species.—Kind of inorganic matter which exists in different species.—Nature and properties of the several inorganic elementary bodies found in plants.

The consideration of the *inorganic* constituents of plants is no less important to the art of culture than the study of their organic elements, which has engaged our sole attention in the preceding part of these lectures.

It has already been shown that when vegetable substances are heated to redness in the air, the whole of the so-called organic elements—carbon, hydrogen, oxygen, and nitrogen—are burned away and disappear; while there remains behind a *fixed* portion, commonly called the ash, which does not burn, and which in most cases undergoes no diminution when exposed to a red heat. This ash constitutes the *inorganic* portion of plants.

The organic or combustible part of plants constitutes, in general, from 88 to 99 per cent. of their whole weight, even after they are dried. Hence the quantity of ash left by vegetable substances in the green state is often exceedingly small. It therefore long appeared to many, that the inorganic matter could be of no essential or vital consequence to the plant—that being, without doubt, derived from the soil, it was only accidentally present,—and that it might or might not be contained in the juices and solid parts of the living vegetable, without materially affecting either its growth or its luxuriance.

Were this the case, however, the quantity and quality of the ash left by the same plant should vary with the soil in which it grew. If one soil contained much lime, another much magnesia, and a third much potash, whatever plant was grown upon these several soils should also contain in greatest abundance the lime, the magnesia, or the potash, which abounded in each locality—and the nature, at least, of the ash, if not its proportion, should be nearly the same in every kind of plant which is grown upon the same soil.

Careful and repeated experiments, however, have shown—

1°. That on whatever soil a plant is grown, if it shoots up in a healthy manner and fairly ripens its seed, the quantity and quality of the ash is nearly the same; and

2°. That though grown on the same soil, the quantity and quality of the ash left by no two species of plants is the same—and that the ash differs the more widely in these respects, the more remote the natural affinities of the several plants from which it may have been derived.

Hence there is no longer any doubt that the inorganic constituents contained in the ash are really essential parts of the substance of plants, —that they cannot live a healthy life or perfect all their parts without them,—and that it is as much the duty of the husbandman to supply these inorganic substances when they are wanting in the soil, as it has always been considered his peculiar care to place within the reach of

the growing plant those decaying vegetable matters which are most likely to supply it with organic food.

For the full establishment of this fact, we are indebted to Sprengel. Others, as De Saussure, have published many important and very useful analyses of the inorganic matters left by plants, but for the illustration of the important practical bearing of this knowledge of their inorganic constituents on the ordinary processes of agriculture, we are, I believe, in a great measure indebted to the writings and numerous analytical researches of Sprengel.

It is difficult to conceive the extent to which the admission of the essential nature and constant quality of the inorganic matter contained in plants, must necessarily modify our notions and regulate our practice in every branch of agriculture. It establishes a clear relation between the kind and quality of the crop, and the nature and chemical composition of the soil in which it grows—it demonstrates what soils ought to contain, and, therefore, how they are to be improved—it explains the effect of some manures in permanently fertilizing, and of some crops in permanently impoverishing the soil—it illustrates the action of mineral substances upon the plant, and shows how it may be, and really is, in a certain measure, *fed* by the dead earth:—over nearly all the operations of agriculture, indeed, it throws a new and unexpected light. Of this, I am confident, you will be fully satisfied when I shall have discussed the various topics I am to bring before you in the present part of my lectures.

§ 1. *Of the relative proportions of inorganic matter in different vegetable substances.*

As above stated, the inorganic matter contained in different vegetable productions varies from 1 to 12 per cent, of their whole weight. The following table exhibits the weight of ash left by 100 lbs. of the more commonly cultivated plants—according to the analyses of Sprengel [*Chemie*, vol. ii., passim]:—

Grain of	Per ct.
Wheat	1·18 lbs.
Rye	1·04
Barley	2·35
Do. dried at 212,	2·52 J.
Oats	2·58
Field Beans	2·14
—— Peas	2·46

Dry straw of	Per ct.
Wheat	3·51 lbs.
Oats	5·74
Barley	5·24
Rye	2·79
Beans	3·12
Peas	4·97

	Undried.	Dried in air.*
Potato	0·83 lbs.	2·65 lbs.
Turnip	0·63	7·05
Do. white	0·8 J.	
Carrot	0·66	5·09
Parsnip	0·82	4·34
Leaf of Potato		4·79
—— Turnip	1·8	2·91
—— do. white	2·18 J.	
—— Carrot	1·98	10·42
—— Parsnip	3·00	15·76
—— Cabbage	0·53	7·55

	Green.	In hay.
Lucerne	2·58 lbs.	9·55 lbs
Red Clover	1·57	7·48
White Clover	1·74	9·13
Rye Grass	1·69	5·3

* Of the substances in this column the potato lost by drying in the air 69 per ct. of water, the turnip 91, the carrot 87, the turnip leaf 86, the carrot leaf, the parsnip, and the parsnip leaf, each 81, and the cabbage leaf 93 per cent.

In the parts of trees dried in the air there are found of inorganic matter—

	Wood.	Leaves.		Wood.	Leaves.
In the Elm . .	1·88	11·8	In the Oak . .	0·21	4·5
Willow .	0·45	8·23	Birch . .	0·34	5·0
Poplar . .	1·97	9·22	Pitch pine	0·25	3·15
Beech . .	0·36	6·69	Comm. furze	0·82	3·1 J.

In looking at the preceding tables, you cannot fail to be struck with one or two points, which they place in a very clear light.

1°. That the quantity of inorganic matter contained in the same weight of the different crops we raise, or of the different kinds of vegetable food we eat, or with which our cattle are fed, is very unlike. Thus 100 lbs. of barley, or oats, or peas, contain twice as much inorganic (earthy and saline matter, that is,) as an equal weight of wheat or rye—and the same is the case with lucerne and white clover hays, compared with the hay of rye grass.

2°. The quantity contained in different parts of the same plant is equally unlike. Thus 100 lbs. of the grain of wheat leave only 1½ lbs. of ash, while 100 lbs. of wheat straw leave 3½ lbs. So the dry bulb of the turnip gives only 7 per cent., while the dry leaf leaves 13 per cent. of ash when it is burned. The dry leaves of the parsnip also contain nearly 16 per cent., though in its root, when sliced and dried in the air, there are only 4½ per cent. of inorganic matter.

In trees the same fact is observed. The wood of the elm contains less than 2 per cent., while its leaves contain nearly 12 per cent.;—the wood of the oak leaves only ⅕th of a per cent., while from its leaves 4½ per cent. or 22 times as much are obtained. The leaves of the willow and of the beech also contain about twenty times as much as the wood of these trees does, when it has been dried under the same conditions.

These differences cannot be the result of accident. They are constant on every soil, and in every climate; they must, therefore, have their origin in some natural law. Plants of different species must draw from the soil that proportion of inorganic matter which is adapted to the constitution, and is fitted to supply the wants of each;—while of that which has been admitted by the roots into the general circulation of the plant, so much must proceed to and be appropriated by each part as is suited to the functions it is destined to discharge. And as from the same soil different plants select different quantities of saline and earthy matter, so from the same common sap do the bark, the leaf, the wood, and the seed, select and retain that proportion which the healthy growth and developement of each requires. It is with the inorganic, as with the organic food of plants. Some draw more from the soil, some less, and of that which circulates in the sap, only a small portion is expended in the production of the flower, though much is employed in forming the stem and the leaves. On the subject of the present section, I shall add two other observations.

1°. From the constant presence of this inorganic matter in plants, and from its being always found in nearly the same proportion in the same species of plants,—a doubt can hardly remain that it is an essential part of their substance, and that they cannot live and thrive without it. But that it really is so, is placed beyond a doubt, by the further experimen-

tal fact, that if a healthy young plant be placed in circumstances where it cannot obtain this inorganic matter, it droops, pines, and dies.

2°. But if it be really essential to their growth, this inorganic matter must be considered as part of the *food* of plants; and we may as correctly speak of feeding or supplying food to plants, when we add earthy and mineral substances to the soil, as when we mix with it a supply of rich compost, or of well fermented farm-yard manure.

I introduce this observation for the purpose of correcting an erroneous impression entertained by many practical men in regard to the way in which mineral substances act when applied to the soil. By the term *manure* they generally designate such substances as they believe to be capable of *feeding* the plant, and hence reject mineral substances, such as gypsum, nitrate of soda, and generally lime, from the list of manures properly so called. And as the influence of these substances on vegetation is undisputed, they are not unfrequently considered as *stimulants* only.

Yet if, as I believe, the use of a wrong *term* is often connected with the prevalence of a wrong *opinion*, and may lead to grave errors in practice,—I may be permitted to press upon your consideration the fact above stated—I may almost say demonstrated—that plants *do feed* upon dead unorganized mineral matter, and that you are, therefore, really manuring your soil, and permanently improving it, when you add to it such substances *of a proper kind.*

§ 2. *Of the kind of inorganic matter found in plants.*

I have said above, *of a proper kind*—for it is not a matter of indifference to a plant, what kind of earthy or saline matter it takes in by its roots. Each species of plant, we have seen, withdraws from the soil a quantity of inorganic matter, which is peculiar to itself, and which, as a whole, is nearly constant.

So also each species, in selecting for itself a nearly constant weight of inorganic matter, while it chooses generally the same kind of saline and earthy ingredients as other plants do, to make up this weight, yet picks them out *in proportions peculiar to itself.* Thus for example, lime is present in the ash of nearly all plants, but while 100 lbs. of the ash of wheat contain 8 pounds of lime, the same weight of the ash of barley contains only 4½ lbs. So also potash is contained in the ash of most plants grown for food, but in the ash of the turnip, there are 37½ per cent. of potash, while in that of wheat there are only 19 per cent. Again, in different parts of the same plant, a like difference prevails. The ash of the turnip bulb contains 16½ per cent. of soda,—that of the leaf, little more than 12 per cent. On the other hand, the lime in that from the bulb constitutes less than 12 per cent. of its weight, while in that of the leaf it amounts to upwards of 34 per cent.

These relative proportions among the different kinds of inorganic matter contained in the ash of plants—like the whole weight itself of the ash—is nearly constant in the same species, and in the same part of a plant, when it is grown in a propitious soil. It is not, therefore, as I have already said, a matter of indifference to the living vegetable, whether it meets with this or with that kind of inorganic matter in the land on which it grows—whether its roots are supplied with lime, or with potash, or with soda. *The soil must contain all these substances, and in such*

quantity as easily to yield to the crop so much of each as the kind of plant specially requires. And if one of these necessary inorganic forms of matter be rare or wholly absent, the crop will as certainly prove sickly or entirely fail, as if the organic food supplied by the vegetable matter of the soil were wholly withdrawn. It is, therefore, as much the end of an enlightened agricultural practice to provide for the various requirements of each crop in regard to inorganic food, as it is to endeavour to enrich the land with purely vegetable substances.

Since, also, as above shown, not only the relative quantity of inorganic matter, but its kind or quality, likewise, is different in different plants,—it may be, that a soil on which one crop cannot attain to maturity may yet surely and completely ripen another—a fact which is proved by every-day experience. The soil, which is unable to supply with sufficient speed all the lime or the potash required for one crop, may yet easily meet the demands of another, and afford an ample return to the husbandman when the time of harvest comes.*

On the other hand, this consoling, at once, and stimulating reflection must arise in the mind of the practical agriculturist from the consideration of the above facts—that if the soil contain all the inorganic substances required by plants, and in sufficient quantity, it will grow, if rightly tilled, any crop which is suited to the climate,—or conversely to make it capable of growing any crop, he has only—along with his usual supplies of animal or vegetable matter—to add in proper quantity these inorganic substances also.

Here a crowd of questions cannot fail to start up in your minds. You will ask, for example,

1°. What are the several inorganic substances usually present in cultivated plants, and what their respective proportions?

2°. Which of them are most generally present in the soil?

3°. In what form can those which are less abundant be added most easily, most advantageously, and most economically?

We shall consider in succession these, and along with them other

* On the same principle, also, some of the interesting facts connected with the grafting of trees are susceptible of a satisfactory explanation.

The root of a tree selects from the soil the *kind* and *quality* of inorganic matter which are required for the healthy maturity of its own parts. Any other tree may be grafted on it, which in its natural state requires the same kind of inorganic matters in nearly the same proportion. This is the case generally with varieties of the same species—more rarely with trees or plants of different species—and least frequently with such as belong to different genera. The lemon may be grafted on the orange, because the sap of the latter contains all the earthy and saline substances which the former requires, and can supply them in sufficient quantity to the engrafted twig. But the fig or the grape would not flourish or ripen fruit on the same stock—because these fruits require other substances than the root of the orange cares to extract from the soil, or in greater quantity than the sap of the orange can supply them.

It is not for want of organic food, for of this the sap of nearly all plants is full—and we have seen in our previous lectures, how the sugar of the fig, the tartaric acid of the grape, and the citric acid of the lemon, may all be produced by natural processes from the same common organic food. When we plant a tree or sow a crop on a soil which does not contain all that the tree or crop requires, the tree must slowly perish,—the crop cannot yield a profitable return. So it is in grafting. *The sap of the stock must contain all that the engrafted leaf or shoot requires in every stage of its growth.* Or to recur to our former illustration—if the potash or lime required by the grape be not taken up and in sufficient quantity by the root of the orange, it will be in vain to graft the former upon the latter with the hope of its coming to maturity or yielding perfect fruit.

This principle may also serve to explain many other curious and hitherto obscure circumstances connected with the practice of the gardener.

subsidiary questions, which will hereafter present themselves to our notice.

§ 3. *Of the several elementary bodies usually met with in the ash of plants*

What is understood by the term element or elementary body among chemists has already been explained (Lect. I., p. 22), as well as the number and names of those elements with which we are at present acquainted.

Of these elementary bodies we have seen that the organic part of plants contains rarely more than four, namely, carbon, hydrogen, oxygen, and nitrogen, in various proportions. In the inorganic part there occur nine or ten others, generally in combination, either with oxygen or with one another.

The names of these inorganic elements are as follow:

Name.	In combination with	Forming
CHLORINE .	Metals	CHLORIDES.
IODINE . .	do.	IODIDES.
SULPHUR .	do.	SULPHURETS.
	Hydrogen	SULPHURETTED HYDROGEN.*
	Oxygen	SULPHURIC ACID.
PHOSPHORUS	do.	PHOSPHORIC ACID.
POTASSIUM .	do.	POTASH.
	Chlorine	CHLORIDE OF POTASSIUM.
SODIUM . .	Oxygen	SODA.
	Chlorine	CHLORIDE OF SODIUM OR COMMON SALT.
CALCIUM .	do.	CHLORIDE OF CALCIUM.
	Oxygen	LIME.
MAGNESIUM	do.	MAGNESIA.
ALUMINIUM	do.	ALUMINA.
SILICON .	do.	SILICA.
IRON and MANGANESE	do.	OXIDES.
	Sulphur	SULPHURETS.

Other elementary bodies, chiefly metallic, occur in some plants—occasionally, and in very small quantity,—but, so far as is yet known, they do not appear to be either necessary to their growth, or to exercise any material influence on the general vegetation of the globe.

Of all the above elementary bodies it may be said, generally,

1°. That with the exception of sulphur,† they are not known to exist or to be evolved, in any quantity, anywhere on the surface of the globe, in their simple, elementary, or uncombined state; and that, therefore, in this state they in no way affect the progress of vegetable growth, or require to occupy the attention of the practical agriculturist.

2°. They all, however, exist in nature more or less abundantly in a state of combination with other substances, and chiefly with oxygen, [for an explanation of the meaning and of the laws of chemical combination, see Lecture II., p. 32]—but in no state of combination are they known to be generally diffused through the atmosphere of the globe, so as to be

* Called also Hydro-sulphuric Acid.

† Given off in vapour from active volcanoes, and from rents and fissures in ancient volcanic countries.

capable of entering plants by their leaves or other superior parts. They must all, therefore, enter by the roots of plants,—must consequently exist in the land,—and must all be necessary constituents of that soil in which the plants that contain them grow.

It will not be necessary, therefore, to consider so much the relative proportions in which these elementary bodies themselves exist in plants, as that of the several chemical compounds which they form with oxygen, or with one another—in which states of combination they exist in the soil, and are found in the circulation and substance of the plant. As a preliminary to this inquiry, however, it will be proper to lay before you a brief outline of the nature and properties of these compound bodies themselves—and of the direct influence they have been found to exercise upon vegetable life.

§ 4. *Of those compounds of the inorganic elements which enter directly into the circulation, or exist in the substance and ash of plants.*

I.—CHLORINE AND MURIATIC ACID.

Chlorine.—If a mixture of common salt and black oxide of manganese [sold by this name in the shops] be put into a flask or bottle of colourless glass, and sulphuric acid (oil of vitriol) be poured upon it, a gas of a greenish-yellow colour will be given off, and will gradually fill the bottle. This gas is distinguished by the name of *chlorine.*

It is readily distinguished from all other substances by its greenish-yellow colour, and its pungent disagreeable smell. It extinguishes a lighted taper, but phosphorus, gold leaf, metallic potassium and sodium, and many other metals, take fire in it and burn of their own accord. It is nearly 4½ times heavier than common air, and therefore may be readily poured from one vessel to another. Water absorbs twice its own bulk of the gas, acquiring its colour, smell, and disagreeable astringent taste.

Animals cannot breathe it without suffocation—and, when unmixed with air, it speedily kills all living vegetables. The solution of chlorine in water was found by Davy to promote the germination of seeds.

It does not exist, and is rarely evolved, [see Lecture V., p. 94,] in nature in a free or uncombined state, and therefore is not known to exercise any *direct* action upon the general vegetation of the globe. It exists largely, however, in common salt (chloride of sodium), every 100 lbs. of this substance containing upwards of 60 lbs. of chlorine. Indirectly, therefore, it may be supposed to influence, in some degree, the growth of plants, where common salt exists naturally in the soil, or is artificially applied in any form to the land.

Muriatic acid, the spirit of salt of the shops, consists of chlorine in combination with hydrogen. It is a gas at the ordinary temperature of the atmosphere, but water absorbs between 400 and 500 times its bulk of it, and the acid of the shops is such a solution in water, of greater or less strength.

Muriatic acid has an exceedingly sour taste, corrodes the skin, and in its undiluted state is poisonous both to animals and plants. It dissolves common pearl ash, soda, magnesia, and limestone, with effervescence; and readily dissolves also, and combines with, many earthy substances which are contained in the soil.

When applied to living vegetables in the state of an exceedingly dilute solution in water, it has been supposed upon some soils, and in some circumstances, to be favourable to vegetation. Long experience, however, on the banks of the Tyne, and elsewhere, in the neighbourhood of the so-called alkali* works, has proved that in the state of vapour its repeated application, even when diluted with much air, is in many cases fatal to vegetable life.

Poured in a liquid state upon *fallow* land, or land preparing for a crop, it may assist the growth of the future grain, by previously forming, with the ingredients of the soil, some of those compounds which have been occasionally applied as manures, and which we shall consider hereafter.

Chlorine is represented by Cl, and muriatic acid by HCl.

II.—IODINE.

Iodine is a solid substance of a lead grey colour, which, when heated, is converted into a beautiful violet vapour. It exists in combination chiefly with sodium, as *Iodide of Sodium*, in sea water and in marine plants; but it has not hitherto been detected in any of the crops usually raised for food.

Like chlorine, it is poisonous both to animals and plants; and was found by Davy to assist and hasten germination. It may possibly exert some hitherto unobserved influence upon vegetation, when it is applied to the soil in districts where sea-ware is largely collected and employed as a manure.

Iodine is slightly soluble in water, and this solution has been mentioned in a previous lecture (VI., p. 107), as affording a ready means of detecting starch by the beautiful blue colour it gives with this substance.

III.—SULPHUR, SULPHUROUS AND SULPHURIC ACIDS, AND SULPHURETTED HYDROGEN.

1°. *Sulphur* is a substance too well known to require any detailed description. In an uncombined state it occurs chiefly in volcanic countries, but it may sometimes be observed in the form of a thin pellicle on the surface of stagnant waters—or of mineral springs, which are naturally charged with sulphurous vapours. In this state it is not known materially to influence the natural vegetation in any part of the globe. It has, however, been employed with some advantage in Germany as a top-dressing for clover and other crops to which gypsum in that country is generally applied. The mode in which it may be supposed to act will be considered hereafter.*

2°. *Sulphurous acid.*—When sulphur is burned in the air it gives off a gaseous substance in the form of white fumes of a well known intensely suffocating odour. These fumes consist of a combination of the sulphur

* In these works carbonate of soda (the common soda of the shops) and sulphate of soda (glauber salt) are manufactured from common salt, and in one of the processes immense quantities of muriatic acid are given off from the furnace, and used to escape into the air by the chimney.

† The refuse heaps of the alkali works on the Tyne contain much sulphur and more gypsum—but the farmers, perhaps, naturally enough, consider that if the works themselves do harm to their crops, the refuse of the works cannot do them much good. There are thousands of tons of this mixture which may be had for the leading away.

which disappears with the oxygen of the atmosphere, and are known to chemists by the name of sulphurous acid. This compound is destructive to animal and vegetable life, but as it is not known to be directly formed to any extent in nature, except in the neighbourhood of active volcanoes, it probably exercises no extensive influence on the general vegetation of the globe.

This gas possesses the curious property of bleaching many animal and vegetable substances. Wool and straw for plaiting are bleached to an almost perfect whiteness—when they are suspended in a vessel or room into which a plate of burning sulphur has been introduced. Gardeners sometimes amuse themselves also in bleaching roses and other red flowers, by holding them over a burning sulphur match. Some shades of red resist this action more or less perfectly, and the colour of the bleached flowers may often be restored—by dipping them in a dilute solution of carbonate of soda, or by holding them over a bottle of hartshorn (liquid ammonia).

3. *Sulphuric acid.*—This is the name by which chemists distinguish the *oil of vitriol* of the shops. It is also a compound of sulphur and oxygen only, and is formed by causing the fumes of sulphur to pass into large leaden chambers along with certain other substances, from which they can obtain a further supply of oxygen.

It is met with in the shops in the form of an exceedingly sour corrosive liquid, which decomposes, chars, and destroys all animal and vegetable substances, and, except when very diluted, is destructive to life in every form. It is rarely met with in nature, in an uncombined state,—though according to Boussingault, some of the streams which issue from the volcanic regions of the Andes are rendered sour by the presence of a quantity of this acid.

It combines with potash, soda, lime, magnesia, &c., and forms *sulphates* which exist abundantly in nature, and have often been beneficially and profitably employed as manures.

Where the soil contains lime or magnesia, the acid may often be applied directly to the land, in a *very* dilute state, with advantage to clover and other similar crops. It has in France, near Lyons, been observed to act favourably when used in this way, while in Germany it has been found better to apply it to the ploughed land, previous to sowing. A few experiments have also been made in this country with partial success. It is deserving, however, of a further trial, and in more varied circumstances.

4°. *Sulphuretted Hydrogen.*—This gaseous compound of sulphur with hydrogen, is almost universally known by its unpleasant smell. It imparts their peculiar taste and odour to sulphurous springs, such as that of Harrogate, and gives their disagreeable smell to rotten eggs. It is often produced in marshy and stagnant places,* and fish ponds, where

* This appears to be especially the case on the coasts of Western Africa, where the hot sun is continually beating on sea water, often shallow, frequently stagnant, and always laden with organic matter, either animal or vegetable (Daniell). Near the mouth of the Tees in this county, where a shallow, dark blue, muddy, samphire-bearing tract stretches for several miles inland from Seaton Snook, the presence of sulphuretted hydrogen may be perceived by the smell, when on a hot summer's day a gentle air skims along the edge of the Slake. The favourable conditions are, a burning sun, a very gentle air, and such a condition of the sea—that those parts and pools which are only reached by the spring tides, shall have been several days uncovered.

vegetable matter is undergoing decay in the presence of water containing gypsum, or other *sulphates*; and it may occasionally be detected by the sense of smell among the roots of the sod, in old pasture land, to which a top-dressing is occasionally given.

As in the egg, so also in other decaying animal substances, especially when the air is in some measure excluded, this gas is formed. In putrified cow's urine, and in night soil, it is present in considerable quantity.

Sulphuretted hydrogen is exceedingly noxious to animal and vegetable life, when diffused in any considerable quantity through the air by which they are surrounded. The luxuriance of the vegetation in the neighbourhood of sulphurous springs, however, has given reason to believe that water impregnated with this gas, may act in a beneficial manner when it is placed within reach of the roots of plants. It seems also to be ascertained that natural or artificial waters which have a sulphurous taste, give birth to a peculiarly luxuriant vegetation, when they are employed in the irrigation of meadows.—[Sprengel, *Chemie*, I., p. 355.]

The relative constitution of these three compounds of sulphur is thus represented:—

One equivalent of	Weighing	Is represented by	Or 1 of Sulphur and
Sulphur	16	S	
Sulphurous Acid . .	32	SO_2	2 of Oxygen
Sulphuric Acid . . .	40	SO_3	3 of Oxygen
Sulphuretted Hydrogen	17	SH	1 of Hydrogen.*

IV.—PHOSPHORUS AND PHOSPHORIC ACID.

1°. *Phosphorus* is a solid substance of a pale yellow colour, and of a consistence resembling that of wax. When exposed to the air it slowly combines with the oxygen of the atmosphere, and burns away with a pale blue flame visible only in the dark. When rubbed, however, or exposed to a slight elevation of temperature, even to the heat of the hand, it readily bursts into a brilliant flame, emitting an intense light accompanied by dense white vapours. It does not occur in nature in an uncombined state, and is not known to be susceptible of any useful application in practical agriculture.

2°. *Phosphoric Acid.*—The white fumes given off by phosphorus, or rather into which it is changed, when burned in the air or in oxygen gas, consist of phosphoric acid. This compound is solid and colourless, attracts moisture from the air with great rapidity, is exceedingly soluble in water, has an intensely sour taste, and like sulphuric acid is capable of corroding and destroying animal and vegetable substances.

It does not exist in nature in a free state, and, therefore, is not *directly* influential upon vegetation. It unites, however, with potash, soda, lime, &c., to form compounds, known by the name of *phosphates*. In these states of combination, it is almost universally diffused throughout nature —and appears to be essentially necessary to the healthy growth and maturity of all living—certainly of all cultivated vegetables.

* For the properties of oxygen and hydrogen see above, pages 24 and 25, and for their equivalent or atomic weights see page 34.

V.—POTASSIUM, POTASH, CARBONATE, SULPHATE, OXALATE, TARTRATE, CITRATE, AND SULPHATE OF POTASH, AND CHLORIDE OF POTASSIUM.

1°. *Carbonate of Potash.*—In countries where non-resinous trees abound, it is usual to burn the wood which cannot otherwise be employed—as in the clearings in Canada and the United States—for the purpose of collecting the ash which remains. This ash is washed with water and the washings boiled to dryness in iron pots. In this state it forms the *pot*-ash of commerce. When this potash is again dissolved in water, and the clear liquid decanted and boiled, the *pearl*-ash of the shops is obtained.

This pearl-ash is an impure form of the *carbonate* of potash of chemists. It readily dissolves in water, has a peculiar taste—distinguished as an *alkaline* taste—and dissolves in vinegar or in diluted sulphuric or muriatic acid, with much *effervescence*. The gas given off during this effervescence (or boiling up) is carbonic acid, the same which, as was shown in a previous lecture, is obtained when a diluted acid is poured upon chalk or common limestone.

This carbonate of potash has been long known to exercise a powerful influence over the growth of plants.

The use of wood-ash as a fertilizer both of pasture and of arable land, goes back to the most remote antiquity; and though the crude wood-ash contains other substances also, yet much of its immediate and most apparent effect is due to the carbonate of potash it contains.

From what has already been stated, at the commencement of the present lecture, in regard to the presence of potash in the parts and juices of nearly all plants, you will already in some measure understand why the carbonate of potash should be useful to vegetation, and—since this alkali (potash) is present in greater quantity in some than in others—why it should appear to be more especially favourable to the growth of one kind of plant than of another.

In this way, it is explained why moss and coarse grasses are extirpated from meadows by a sprinkling of wood ashes—and why red clover, lucerne, esparsette, beans, peas, flax, and potatoes, &c., are greatly promoted in their growth by a similar treatment. This substance, however, has other functions to perform in reference to vegetation, besides that of simply supplying the crop with the potash it requires; these functions I shall explain more particularly hereafter, when you will perhaps be better prepared for understanding the details into which it will be necessary to enter.

2°. *Potash.*—When 12 parts of carbonate of potash are dissolved in water, and boiled with half their weight of newly-slaked quick-lime, they are gradually deprived of their carbonic acid, and converted into pure potash,—or as it is often called, from its effect on animal and vegetable substances, *caustic potash*.

The caustic liquid thus obtained decomposes or dissolves most animal and vegetable substances, whether living or dead. When applied to the skin, unless it be in a very diluted state, it destroys it, and produces a painful sore. Potash does not occur in nature in this caustic or uncombined state, and is not known, therefore, to exercise any *direct* influence upon natural vegetation.

When wood-ashes and quick-lime are mixed together in artificial

composts, it is not unlikely that a portion of the carbonate of potash may be rendered caustic, and, therefore, be more fit to act upon the vegetable matter in contact with it—by rendering it soluble in water and thus capable of entering into the roots of plants. To this point I shall have occasion to return hereafter. In the mean time, it is proper to remark, that if pearl-ash be mixed, as above prescribed, with half its weight of quick-lime, and then boiled with *less than ten or twelve times its weight of water, a part of the potash only is rendered caustic*—the lime being unable to deprive the pearl-ash (carbonate of potash) of its carbonic acid, unless it be largely diluted. Hence, in dry composts, or mixtures of this substance with quick-lime, it is unlikely that any large portion of the potash can be at once brought to the caustic state. This fact is really of importance in reference to the theory of the conjoined action of quick-lime and wood or pearl-ash, when mixed together in artificial manures, and applied to the land.

3°. *Potassium.*—When dry caustic potash, obtained by evaporating the caustic solution above described, is mixed with powdered charcoal and iron filings, and exposed to an intense heat in an iron retort, it is decomposed, and metallic *potassium* distils over, and is collected in the form of white shining silvery drops.

It was one of the most remarkable discoveries of Sir H. Davy, that potash was a compound substance, and consisted of this metal potassium united to oxygen gas.

Potassium is remarkable for the strong tendency it possesses to unite again with oxygen and re-form potash. When simply exposed to the air, it gradually absorbs oxygen from the atmosphere; but if it be heated in the air, it takes fire and burns. When the combustion has ceased, a quantity of *caustic* potash remains, the weight of which is nearly one-fifth greater than that of the potassium employed. It even bursts into a flame when thrown upon water, depriving that liquid of its oxygen, and liberating its hydrogen,—and it was justly considered as the most astonishing property of this metal, when first discovered, that it took fire when placed upon the coldest ice. [For the composition of water, see Lecture II., p. 36.] When thus burned in contact with water, potash is formed, as before, and is found dissolved in the liquid when the experiment is completed.

4°. *Chloride of Potassium.*—This is a compound of chlorine with potassium, which, in taste, properties, and general appearance, has much resemblance to common salt. It may be formed by dissolving pearl-ash in dilute muriatic acid (spirit of salt) as long as any effervescence appears, and afterwards evaporating to dryness. It exists in small quantity in sea water, in the ash of most plants, and frequently in the soil. It is not an article of manufacture, but is occasionally extracted from kelp, and sold to the alum makers. Could it be easily and cheaply obtained, there is no doubt that it might be employed with advantage as a manure, and especially in those circumstances in which common salt has been found to promote vegetation. The refuse of the soap-boilers, where soap is made from kelp, contains a considerable quantity of this compound. This refuse might be obtained at a cheap rate, and, therefore, might be usefully collected and applied to the land where such works are established.

5°. *Sulphate of Potash.*—This compound is formed by adding pearl-ash to dilute sulphuric acid (oil of vitriol) as long as effervescence appears, and then evaporating the solution. It is a white saline substance, sparingly soluble in water, and has a disagreeable bitterish taste. It exists in considerable quantity in wood-ash, and in the ash of nearly all plants, and is one of the most abundant impurities in the common potash and pearl-ash of the shops. This sulphate itself is not an article of extensive manufacture, but it exists in common alum to the amount of upwards of 18 per cent. of its weight.

Dissolved in 100 times its weight of water, the sulphate of potash has been found to act favourably on red clover, vetches, beans, peas, &c., and part of the effect of wood ashes on plants of this kind is to be attributed to the sulphate of potash they contain. Turf ashes are also said to contain this salt in variable quantity, and to this is ascribed a portion of their efficacy also when applied to the land.

6°. *Nitrate of Potash*, or saltpetre, is a well known saline substance, of which mention has already been made in the preceding lectures. [See p. 56, and pp. 159 to 163.] It contains potash and nitric acid only, and may be readily formed by dissolving pearl-ash in nitric acid, and evaporating the solution. It exists, and is continually reproduced in the soil of most countries, and is well known to exercise a remarkable influence in accelerating and increasing the growth of plants.

7°. *Oxalates of Potash.*—These salts exist in the common and wood sorrels, and in most of the other more perfect plants in which oxalic acid is known to exist. [See pp. 47 and 137.] The *salt of sorrel* is the best known of these oxalates. This salt has an agreeable acid taste, and is not so poisonous as the uncombined oxalic acid.

When this salt is heated over a lamp, the oxalic acid it contains is decomposed, and carbonate of potash is obtained. It is supposed that a great part of the potash extracted from the ashes of wood and of the stems of plants in general, in the state of carbonate, existed as an oxalate in the living tree, and was converted into carbonate during the combustion of the woody fibre and other organic matter. This compound, therefore, in all probability, performs an important part in the changes which take place in the interior of plants, though its direct agency in affecting their growth when applied externally to their roots has not hitherto been distinctly recognized. It is probably formed occasionally in farm-yard manure, and in decaying urine and night-soil, but nothing very precise is yet known on this subject.

8°. *Citrates and Tartrates of Potash.*—These salts exist in many fruits. The citrates abound in the orange, the lemon, and the lime—the tartrates in the grape. When heated over a lamp, they are decomposed, and like the oxalates leave the potash in the state of carbonate.

In the interior of plants, both potash and soda are most frequently combined with organic acids (oxalic, citric, tartaric, &c., for an account of the most abundant of which see Lecture VI., p. 121,) and the compounds thus formed are generally what chemists call *acid* salts—that is to say, they generally have a distinctly sour taste, redden vegetable blues, and contain much more acid than is found to exist in certain other well known compounds of the same acids with potash.

The citrates and tartrates are not known to be formed in nature, ex-

cept in the living plant, and as they are too expensive to be ever employed as manures, it is the less to be regretted that few experiments have yet been tried with the view of ascertaining their effect upon vegetation.

9°. *Phosphates of Potash.*—If to a known weight of phosphoric acid (p. 186) pearl-ash (carbonate of potash) be added as long as any effervescence appears, and the solution be then evaporated, *phosphate* of potash is obtained. If to the solution before evaporation a second portion of phosphoric acid be added, equal to the first, and the water be then expelled by heat, *bi-phosphate* of potash will remain, [so called from *bis*, twice, because it contains *twice* as much acid as the former, or *neutral* phosphate.]

One or other of these two salts is found in the ash of nearly all plants. Whether or not the elements of which they consist exist in this state of combination in the living plant will be considered hereafter; in the mean time it may be stated as certain that they are of the most vital importance not only in reference to the growth of plants themselves, but also to their nutritive qualities when eaten by animals for food.

These phosphates are occasionally, perhaps very generally, present in the soil in minute quantities, and there is every reason to believe that could they be applied to the land in a sufficiently economical form, they would in many cases act in a most favourable manner upon vegetation. They are contained in urine and other animal manures, and to their presence a portion of the efficacy of these manures is to be ascribed.

VI.—SODIUM, SODA, CARBONATE OF SODA, SULPHATE OF SODA, SULPHURET OF SODIUM, CHLORIDE OF SODIUM.

1°. *Chloride of Sodium*, common or sea salt, exists abundantly in sea water, and is found in many parts of the earth in the form either of incrustations on the surface or of solid beds or masses at considerable depths. The rock salt of Cheshire is a well known example of this latter mode of occurrence.

Common salt may also be detected in nearly all soils, it is found in the ashes of all plants, but especially and in large quantity in the ashes of marine plants (kelp), and is sometimes borne with the spray of the sea to great distances inland, when the winds blow strong, and the waves are high and broken.

On some rocky shores, as on that between Berwick and Dunbar, the spray may be seen occasionally moving up the little coves and inlets in the form of a distinct mist driving before the wind, and the saline matter has been known to traverse nearly half the breadth of the island before it was entirely deposited from the air.

It is impossible to calculate how much of the saline matter of sea water may in this way be spread over the surface of a sea-girt land like ours; but two things are certain—that those places which are nearer the sea will receive a greater, and those more inland a lesser, portion; and that those coasts on which sea winds prevail will be more largely and more frequently visited than those on which land winds are more commonly experienced.

It is well known that common salt has been employed in all ages and in all countries for the purpose of promoting vegetation, and in no coun-

try perhaps in larger quantity or more extensively than in England. That it has often failed to benefit the land in particular localities, only shows that the soil in those places already contained a natural supply of this compound large enough to meet the wants of the crops which grew upon it. The facts above stated as to the influence of the wind in *top-dressing* the exposed coast-line of a country with a solution of salt, may serve as an important guide both in reference to the places in which it may be expected to benefit the land, and to the causes of its failing to do so in particular districts.

2°. *Sulphate of Soda*, or Glauber's salt, is usually manufactured from common salt by pouring upon it diluted sulphuric acid (oil of vitriol), and applying heat. Muriatic acid (spirit of salt, so called by the old chemists, because thus given off by common salt,) is given off in the form of vapour, and sulphate of soda remains behind. It may also be prepared, though less economically, by adding the common soda of the shops to diluted sulphuric acid as long as any effervescence appears.

This well known salt is met with in variable quantity in the ashes of nearly all plants, and is diffused in minute proportion through most soils. I have elsewhere [see Appendix,] directed your attention to the beneficial effect which it has been observed to exercise on the growth especially of such plants as are known to contain a considerable proportion of sulphuric acid. Among these are red clover, vetches, peas, &c. And as this salt is manufactured largely in this country, and can be obtained at the low price of ten shillings a cwt. in the dry state,* I have recommended it to the practical farmer as likely to be extensively useful as a manure for certain crops and on certain soils. The kind of crops and soils have as yet in great measure to be determined by practical trials.—[See the results of Mr. Fleming's Experiments, given in the Appendix.]

3°. *Sulphuret of Sodium.*—When sulphate of soda is mixed with saw-dust, and heated in a furnace, the oxygen of the salt is separated, and sulphuret of sodium is produced. By a similar treatment sulphate of potash is converted into sulphuret of potassium. These compounds consist of sulphur and metallic sodium or potassium only. They do not occur extensively in nature, and are not manufactured for sale; but there is reason to believe that they would materially promote the vegetation of such plants as contain much sulphur in combination with potash or soda. The sulphuret of sodium is present in variable quantity in the refuse lime of the alkali works, already spoken of, and might be expected to aid the other substances of which it chiefly consists, in contributing to the more rapid growth of pulse and clover crops.

4°. *Carbonate of Soda.*—I have described the above compounds of soda before mentioning this its best known and most common form, because they are all steps in the process by which the latter is usually prepared from common salt, by the soda manufacturers.

When the sulphuret of sodium is mixed with chalk in certain proportions, and heated in a furnace, it is deprived of its sulphur, and is converted into *carbonate* of soda, the common soda of the shops.

This well known salt, now sold in the state of crystals, [containing 62

* Not in crystals, the form in which it is commonly sold as a horse medicine. These crystals contain upwards of half their weight (55 per cent.) of water.

per cent. of water,] at from 10s. to 12s. a cwt., has not as yet been extensively tried as a means of promoting vegetation. The lowness of its price, however, and the fact that it is an article of extensive home manufacture, conjoined with the encouragement we derive from theoretical considerations—all unite in suggesting the propriety of a series of experiments with the view of determining its real value to the practical agriculturist. The mode in which theory indicates that this compound is likely to act in promoting vegetation—as well as the crops to which it may be expected to be especially useful, will come under our consideration hereafter.

Besides the common carbonate of soda above described, and which in the neighbourhood of Newcastle is manufactured from common salt to the amount of 30 or 40 thousand tons every year, there occur in nature two other compounds of soda with carbonic acid, in which the latter substance is present in larger quantity than in the soda of the shops. The *sesqui*-carbonate, containing one half more carbonic acid, occurs in the soil in many warm climates (Egypt, India, South America, &c.), and at Fezzan, in Africa, is met with as a mineral deposit of such thickness as in that dry climate to allow of its being employed as a building stone.

The *bi*-carbonate is contained in the waters of many lakes, in Hungary, in Asia, &c., and in many springs in all parts of the world. There can be no doubt that the waters of such springs are fitted to promote the fertility, especially of pasture land, to which they may be applied either by artificial irrigation, or by spontaneous overflow from natural outlets. Some of the Harrowgate waters contain a sensible quantity of this bicarbonate, and over a large portion of the Yorkshire coal-field, a bed of rock is found, at various depths, the springs from which hold in solution a considerable portion of this salt. The Holbeck water of Leeds, according to Mr. West, owes its softness to the presence of this carbonate, and the water from the coal-mines in the neighbourhood of Wakefield is occasionally so charged with it, as to form troublesome saline incrustations on the bottoms of the steam boilers. Where these waters occur in sufficient abundance, they should not be permitted to escape into the rivers, until they have previously been employed in irrigating the land.

It has occasionally been observed that natural springs in some localities impart a degree of luxuriance to natural pasture, which is not to be accounted for by the mere effect of a constant supply of water. In such cases, the springs may be expected to contain some alkaline, or other mineral ingredient, which the soil is unable to supply to the plants which grow upon it, either in sufficient abundance, or with sufficient rapidity.

5°. *Soda or Caustic Soda.*—When a solution of the common soda of the shops is boiled with quick-lime, it is deprived of its carbonic acid, and like the carbonate of potash (p. 187) is brought into the *caustic* state. In this state it destroys animal and vegetable substances, and, unless very dilute, is injurious to animal and vegetable life.

When common salt (chloride of sodium) is mixed with quick-lime in compost heaps, it is deprived by the lime of a portion of its chlorine, and is partially converted into this caustic soda. The action of the soda in this state is similar to that of caustic potash. Not only does it readi-

ly supply soda to the growing plant, to which soda is necessary, but it also acts upon certain other substances which the plants require, so as to render them soluble, and to facilitate their entrance into the roots of plants. To the presence of soda in this caustic state, the efficacy of such composts of common salt and lime in promoting vegetation, is in part to be ascribed.

6°. *Sodium* is a soft metal of a silver white colour, and, like potassium, light enough to float upon water. It is obtained by heating caustic soda with a mixture of charcoal and iron filings. It takes fire upon water—though not so readily as potassium—and combines with its oxygen to form soda. In the metallic state it is not known to occur in nature, and, therefore, does not directly act upon vegetation. With oxygen it forms soda,—with chlorine, chloride of sodium (common salt),—and with sulphur, sulphuret of sodium,—all of which, as already stated, are more or less beneficial to vegetation.

7°. *Phosphates of Soda.*—When the common soda of the shops is added to a solution of phosphoric acid in water, till effervescence ceases, and the solution is evaporated to dryness, phosphate of soda is formed, and by the subsequent addition of as much more phosphoric acid—*bi*-phosphate. These salts occur more or less abundantly in the ash of nearly all plants; they are occasionally also detected in the soil, and one or other of them is almost always present in urine and other animal manures. As we know from theory that these compounds must be grateful to plants, we are justified in ascribing a portion of the efficacy of animal manures, in promoting the growth of vegetables, to the presence of these phosphates, as well as to that of the phosphates of potash (p. 190). They are not known to occur in the mineral kingdom in any large quantity, neither are they articles of manufacture, hence their direct action upon vegetation has not hitherto been made the subject of separate experiment.

VII.—CALCIUM, LIME, CARBONATE OF LIME, SULPHATE OF LIME, NITRATE OF LIME, PHOSPHATES OF LIME, CHLORIDE OF CALCIUM, SULPHURET OF CALCIUM.

1°. *Carbonate of Lime.*—Chalk, marble, and nearly all the limestones in common use, are varieties, more or less pure, of that compound of lime with carbonic acid which is known to chemists as carbonate of lime. It occurs of various colours and of various degrees of hardness, but in weight the compact varieties are very much alike, being generally a little more than 2½ times (2·7) heavier than water. They all dissolve with effervescence in dilute muriatic acid (spirit of salt), and by the bubbles of gas which are seen to escape when a drop of this acid is applied to them, limestones may in general be readily distinguished from other varieties of rock. They dissolve slowly also in water which holds carbonic acid in solution; and hence the springs which issue from the neighbourhood of deposits of limestone are generally charged in a high degree with this mineral substance.

The value of this carbonate of lime in rendering a soil capable of producing and sustaining a luxuriant vegetation depends, in part, it is true, on the necessity of a certain proportion of lime to the growth and full developement of the several parts of nearly all plants, but it performs also

other important offices, which we shall hereafter have occasion more fully to consider.

2°. *Lime or Quick-lime.*—When limestone is burned along with coal or wood in kilns so constructed that a current of air can pass freely through them, the carbonic acid is driven off, and the lime alone remains. In this state it is generally known by the name of burned or *quick*-lime, from its caustic qualities, and is found to have lost nearly 44 per cent. of its original weight.

The most remarkable property of quick-lime is its strong tendency to combine with water. This is displayed by the eagerness with which this liquid is drunk in by the lime in the act of slaking, and by the great heat which is at the same time developed. Slaked lime is a compound of lime with water, and by chemists is called a *hydrate* of lime. It contains 24 per cent. of its weight of water.

The action of quick-lime upon the land is one of the most important which presents itself to the observation of the practical agriculturist. Among other effects produced by it is that of hastening the decomposition of vegetable matter either in the soil or in compost heaps; but this effect is materially promoted by—if it be not wholly dependent upon—the presence of air and moisture. By this decomposition carbonic acid and other compound substances are produced, which the roots are capable of absorbing and converting into the food of plants.

In this caustic state lime does not occur in nature, nor when exposed to the air does it long remain in this state. It gradually absorbs carbonic acid from the atmosphere, and is again converted into carbonate. This change takes place more or less rapidly in all cases where quick-lime is applied to the land, but the benefits arising from burning the lime do not disappear when it is thus reconverted into carbonate. On the contrary, the state of very fine powder, into which quick-lime falls on slaking, enables the carbonate of lime, subsequently formed, to be intermixed with the soil in a much more minute state of division than could be obtained by any mechanical means. This we shall hereafter see to be a most important fact, when we come to study in more detail the theory of the action of lime in the several states of combination, and under the varied conditions in which it is employed for the purpose of improving the land.

3°. *Calcium* is a silver-white metal, which, by its union with oxygen, forms *lime*. It is not known to exist in nature in an uncombined state, is prepared artificially only with great difficulty, and therefore exercises no direct action on vegetable growth.

4°. *Chloride of Calcium.*—When chalk or quick-lime is dissolved in muriatic acid, a solution of *chloride of calcium* is obtained. This solution occurs in sea-water, in the refuse (mother-liquor) of the salt-pans, and is allowed to flow away in large quantities as a waste from certain chemical works. I have elsewhere stated the effects it has been observed to produce upon vegetable growth, [see Appendix,] and have recommended the propriety of making experiments with the view of rendering useful some of those materials which in our manufactories are now suffered largely to run to waste.

5°. *Sulphuret of Calcium* is a compound of sulphur and calcium, which may be formed by heating together chalk and sulphur in a covered

crucible. It is sometimes produced in nature, where moist decaying vegetable and animal matters are allowed to ferment in the presence of gypsum; it may sometimes also be detected in the soil, and in the waters of mineral springs, and is contained largely in the recent refuse heaps of the alkali works. Like the sulphurets of potassium and sodium, already described, it is fitted, when judiciously applied, to promote the growth especially of those plants in which sulphur has been recognized as a necessary constituent.

6°. *Sulphate of Lime*, or gypsum, is a well known white crystalline or earthy compound, which occurs as an abundant mineral deposit in numerous parts of the globe. It is present in many soils, is contained in the waters which percolate through such soils, and in those of springs which ascend from rocky beds in which gypsum exists, and is detected in sensible proportions in the ashes of many cultivated plants. It is extensively employed in the arts, and in some countries not less extensively as a means of promoting the fertility of the land.—[See Appendix, p. 1.]

The gypsum of commerce contains nearly 21 per cent. of its weight of water, which it loses entirely on being exposed to a red heat. In some countries, a variety which is almost entirely free from water occurs in rocky masses, and is distinguished by the name of *Anhydrite*.

Gypsum, when burned, has the property of being reduced with great ease into the state of an impalpable powder. This powder, however, combines so readily with the 21 per cent. of water it had previously lost, that if it be mixed with water to the consistence of a paste so thin that it can be poured into a mould, it sets and hardens in a few minutes into a solid mass. In this way burned gypsum is employed in making plaster casts and cornices.

Burned gypsum consists of lime and sulphuric acid only—in the proportions of 41½ of the former, to 58½ of the latter. Its use as a manure, therefore, will be specially to promote the growth of those plants by which these two substances are more abundantly required, and upon soils in which they are already present in comparatively small proportion.

7°. *Nitrate of Lime*.—The production of nitrate of lime in artificial nitre-beds, on old walls, and on the sides of caves and cellars, especially in damp situations, has already been alluded to in Lecture VIII., [p. 161.] It may be formed artificially by dissolving common limestone in nitric acid, and evaporating the solution. It constitutes a white mass, which rapidly attracts water from the air, and runs to a liquid. It is produced naturally, and exists, as I believe, in soils containing lime, more commonly than has hitherto been suspected. Its extreme solubility in water, however, renders it liable to be carried downwards into the lower portions of the soil by every shower of rain—or to be actually washed away, when long continued wet weather prevails.

When heated to dull redness with vegetable matter, the nitrate of lime is decomposed, and is converted into carbonate, or when exposed alone to a bright red heat, the nitric acid is expelled, and quick-lime alone remains. Hence where it really exists in plants, it cannot be detected in the ash,—and when present in soils, it must be separated by

washing them in water, before they are exposed to a heat sufficient to burn away the organic matter they contain.

The details already entered into in the preceding lecture (pp. 159 to 163) regarding the general action of nitric acid, in promoting the natural vegetation of the globe, render it unnecessary for me to dwell here on the special action of its compound with lime—more particularly as the entire subject of the action of lime upon the land will hereafter demand from us a separate consideration.

The nitrate of lime cannot, as yet, be formed by art, at a sufficiently cheap rate to allow of its being manufactured for the use of the agriculturist.

Phosphates of Lime.—Lime combines with phosphoric acid in several proportions, forming as many different compounds. Of these by far the most important and abundant in nature, certainly the most useful to the agriculturist, is the *earth of bones*. It will be necessary, however, to advert shortly to two others, with the existence of which it is important for us to be acquainted.

A. *Earth of Bones* is the name given to the white earthy skeleton that remains when the bones of animals are burned in an open fire until every thing combustible has disappeared. This earthy matter consists chiefly of a peculiar phosphate of lime, composed of 51½ per cent. of lime, and 48½ of phosphoric acid. This compound exists ready formed in the bones of all animals, and is the substance selected in the economy of nature to impart to them their strength and solidity. It is found in smaller quantity in those of young animals, while they are soft, and cartilaginous,—and the softening of the bones, which in after-life occurs as the result of disease, is caused by the unnatural abstraction of a greater portion of this earthy matter than is replaced by the food.

This earthy phosphate constitutes about 57 per cent. of the dried bones of the ox, is present in lessér quantity in the horns, hoofs and nails, and is never absent even from the flesh and blood of healthy animals. It exists in the seed of many plants, in all the varieties of grain which are extensively cultivated for food, and in the ashes of most common plants. The ashes of leguminous, cruciferous, and composite plants, are especially rich in this compound.

If we consider that when animals die, their bones are chiefly buried in the earth, and that over the entire globe, animal life, in one or other of its forms, prevails, we shall not be surprised that, in almost every soil, the earth of bones should be found to exist in greater or less abundance. Nor can we have any difficulty in conceiving, if such be the case, whence plants draw their constant and necessary supplies of this substance.

At the same time, it is true of this compound, as of all the others we have yet spoken of, as occurring in, and as necessary to the growth of, vegetables,—that some soils contain it in greater abundance than others, and that from some soils, therefore, certain plants will not readily obtain as much of this substance as they require. This is the natural principle on which the use of bone-dust as a manure chiefly depends.

Hence of two marls both containing carbonate of lime, that will be most useful to the land which contains also, as many do, a notable portion of phosphate of lime; and of two limestones, that will be preferred

in an agricultural district in which animal remains most abound. I shall have occasion to illustrate this point more fully, when in a subsequent lecture I come to explain the natural origin of soils, and to trace their chemical constituents to the several rocky masses from which they appear to have been derived.

Before dismissing this topic, however, there are one or two properties of this bone earth which are of practical importance, and to which, therefore, I must shortly request your attention. It is insoluble in water or in solutions of soda or potash, but it dissolves readily in acids, such as the nitric or muriatic, and also, though less easily and abundantly, in common vinegar. It exists in milk, and is supposed to be held in solution by a peculiar acid found in this liquid, and which is distinguished by the name of *lactic acid* (acid of milk).

It is slightly soluble also in a solution of carbonic acid, and of certain other organic acids which exist in the soil, and it is by means of these acids that it is supposed to be rendered capable of entering into the roots of plants. Wherever vegetable matter exists, and is undergoing decay in the soil, the water makes its way to the roots more or less laden with carbonic acid, and thus is enabled to bear along with it not only common carbonate of lime, as has been shown in a previous lecture (p. 47), but also such a portion of phosphate as may aid in supplying this necessary food to the growing plant.*

In the bones of animals the phosphate is associated with animal *gelatine*, which can be partially extracted by boiling bones in water under a high pressure. It has been observed, however, that the phosphate, when in a minute state of division, is slightly soluble in a solution of gelatine, and hence bones, from which the jelly has been partially extracted by boiling, will be deprived of a certain proportion of their earthy matter also. They will have lost their gelatine, however, in a greater proportion, and hence, *if again thoroughly dried*, they will contain a larger per-centage of bone earth than when in their natural state. In this country, bones are seldom boiled, I believe, either for the jelly they give, or as in France and Germany for the manufacture of glue, though in certain localities they are so treated in open vessels for the sake of the oil they are capable of yielding. Such boiled bones are said to act more quickly when applied to the land, but to be less permanent in their effects. This may be chiefly owing to their not being so perfectly dry as the unboiled bones. Being thus moist, they will contain, in the same weight, a comparatively smaller quantity both of the animal gelatine

* If to a solution of bone earth in muriatic acid (spirit of salt), liquid ammonia (hartshorn) be added, the solution will become milky, and a white powder will fall, which is the earth of bones in an extremely minute state of division. If this powder be washed by repeated affusions of pure water, and be afterwards well shaken with water which is saturated with carbonic acid, or through which a current of this gas is made to pass, a sensible portion of the phosphate will be found to be taken up by the water. This will appear on decanting the solution and evaporating it to dryness, when a quantity of the white powder will remain behind. The mean of 10 experiments made in this way gave me 30 grains for the quantity of phosphate taken up by an imperial gallon of water. What takes place in this way in our hands, happens also in the soil. Not only does that which enters the root bear with it a portion of this compound where it exists in the soil, but the superabundant water also which runs off the surface or sinks through to the drains, carries with it to the rivers in its course a still larger quantity of this soluble compound, and thus gradually lessens that supply of phosphate which either exists naturally in the soil, or has been added as a manure by the practical agriculturist.

and of the earthy phosphate, while they will also be more susceptible of speedy decomposition when buried in the soil.*

In solutions of common salt and of sal-ammoniac, the earth of bones is also slightly soluble, and cases may occur where the presence of these compounds in the soil may facilitate the conveyance of the earthy phosphate into the roots of plants.

B. *Acid or* Bi-*Phosphate of Lime.*—When burned bones are reduced to powder, and digested in sulphuric acid (oil of vitriol), diluted with once or twice its weight of water, the acid combines with a portion of the lime, and forms sulphate of lime (gypsum), while the remainder of the lime and the whole of the phosphoric acid are dissolved. The solution, therefore, contains an *acid* phosphate of lime, or one in which the phosphoric acid exists, in much larger quantity than in the earth of bones. The true bi-phosphate, when free from water, consists of 71½ of phosphoric acid, and 28½ of lime. It exists in the urine of most animals, and is therefore an important constituent of liquid manures of animal origin.

If the mixture of gypsum and acid phosphate, above described, be largely diluted with water, it will form a most valuable liquid manure, especially for grass land, and for crops of rising corn. In this liquid state, the phosphoric acid will diffuse itself easily and perfectly throughout the soil, and there will speedily lose its acid character by combining with one or other of the *basic*† substances, almost always present in every variety of land.

Or if to the solution, before it is applied to the land, a quantity of pearl-ash be added until it begin to turn milky, a mixture of the phosphates with the sulphates of lime and of potash will be obtained, or—if soda be added instead of potash—of the phosphates with the sulphates of lime and of soda; either of which mixtures will be still more efficacious upon the land, than the solution of the acid phosphates alone.

Or to the solution of bones in the acid, the potash or soda may be added without further dilution, and the whole then dried up by the addition of charcoal powder, or even of vegetable mould, till it is in a sufficiently dry state to be scattered with the hand as a top-dressing, or buried in the land by means of a drill.

I have above alluded to the employment of bones in France and Germany, for the manufacture of glue. For this purpose the broken bones are digested in weak muriatic acid, by which the earthy matter is dissolved, and the gelatine left behind. The gelatinous skeleton is boiled down for glue, and the solution of the bone earth is thrown away. This solution contains a mixture of the *acid* phosphate of lime with chloride of calcium,—and might be used up in any of the ways above described, with manifest benefit to the land. The glue prepared by this method, however, is said to be inferior in quality, and as the process is not adopted in this country, the opportunity of making an economical application of this waste material is not likely to be often presented to the English farmer.

* The relative value of crushed bones in these two states, is indicated by the price of the unboiled being about 7 guineas, while that of boiled is only about 4 guineas a ton.

† This word has already been used and explained—it is applied to potash, soda, ammonia, lime, magnesia, and other substances, which have the property of combining with acids (sulphuric, nitric, &c.) and of thus *neutralising* them, or depriving them of their acid qualities and effects.

C. *Native Phosphate of Lime or Apatite.*—In some parts of the world, a hard mineral substance, commonly known by the name of Apatite, occurs in considerable quantity. It consists chiefly of a phosphate of lime, which differs but slightly in its constitution from the earth of bones, —containing 54½ per cent. of lime, while the latter contains only 51½ per cent. The composition of this mineral would lead us to expect it to possess a favourable action upon vegetation, and this anticipation has been confirmed by some experiments made with it on a limited scale by Sprengel.—[*Chemie*, I., p. 64.]

It occurs occasionally in mineral veins, especially such as are found in the granitic and slate rocks. Masses of it are met with in Cumberland, in Cornwall, in Finland, in the iron mines of Arendahl in Norway, and in many other localities. A variety of it distinguished by the name of *phosphorite* is said to form beds at Schlachenwalde in Bohemia, and in the province of Estremadura in Spain. From the last of these localities being the most accessible, the time may come when the high price of bones may induce our enterprising merchants to import it, for the purpose of being employed in a finely powdered state as a fertilizer of the land.

¼ of Grape Sugar.	3 of Water

LECTURE X.

Inorganic constituents of plants continued.—Magnesia, Alumina, Silica, and the Oxides of Iron and Manganese.—Tabular view of the constitution of the inorganic substances described.—Proportions in which these several substances are found in the plants cultivated for food.—Extent to which these plants exhaust the soil of inorganic vegetable food.—State in which the inorganic elements exist in plants.

§ 1. *Inorganic constituents of plants continued.*

VIII.—MAGNESIUM, MAGNESIA, CARBONATE, SULPHATE, NITRATE, AND PHOSPHATE OF MAGNESIA, CHLORIDE OF MAGNESIUM.

1°. *Carbonate of Magnesia* is a tasteless earthy compound, which in some parts of the world forms rocky masses and veins of considerable height and thickness. It occurs more largely, however, in connection with carbonate of lime in the magnesian limestones, so well known in the eastern and northern parts of England,—and in similar rocks, distinguished by the name of *dolomites* or of dolomitic limestones, in various countries of Europe. The pure, exceedingly light, white magnesia of the shops, is partly extracted from the magnesian limestone, and partly from the mother liquor of the salt pans, which generally contains much magnesia.

When pure and dry, carbonate of magnesia consists of $43\frac{1}{3}$ of magnesia, and $51\frac{2}{3}$ of carbonic acid. It dissolves readily in diluted acids (sulphuric, muriatic, and acetic,) the carbonic acid at the same time escaping with effervescence.

Existing as it does in many solid rocks, this carbonate of magnesia may be expected to be present in the soil, and it is found in the ashes of many plants. Of the ashes of some parts of plants it constitutes one-sixth of the entire weight.

When exposed to the air in a finely divided state, it gradually absorbs a quantity of moisture from the atmosphere, equal to two-thirds of its own weight. In this state, it dissolves in 48 times its weight of water, though, when dry, it is nearly insoluble. Like carbonate of lime it is also soluble in water impregnated with carbonic acid, but in a somewhat greater degree. In this state of solution it may be readily carried into the roots, and be the means of supplying to the parts of living vegetables a portion of that magnesia which is necessary to their perfect growth.

Soils containing much of this carbonate of magnesia are said to be highly absorbent of moisture, and to this cause is ascribed the *coldness* of such soils.—[Sprengel, *Chemie*, I., p. 645.] This opinion is, however, open to doubt.

2°. *Magnesia or Caustic Magnesia, the calcined magnesia of the shops.*—When the carbonate of magnesia is heated to redness in the open air, it parts with its carbonic acid much more readily than lime does, and is brought into the state of pure or caustic magnesia. In this state it does not occur in nature, but it is occasionally met with in com-

bination with about 30 per cent. of water. When magnesian limestones or dolomites are burned, the quick-lime obtained often contains caustic magnesia also in considerable quantity. This mixture is frequently applied to the land, and, as is well known in many parts of England, with injurious effects, if laid on in too large quantities. The cause of this hot or burning nature, as it is called, of magnesian lime, is not very satisfactorily ascertained. I shall, however, state two or three facts, which may assist in conducting us to the true cause.

1°. Quick-lime dissolves in 750 times its weight of water, at the ordinary temperature of the atmosphere, while pure magnesia requires 5142 times its weight. The magnesia, therefore, is not likely to injure living plants *directly* by entering into their roots in its *caustic* state, since lime which is seven times more soluble produces no injurious effect.

2°. It seems to be the result of experience, that magnesia in the state of carbonate is but slightly injurious to the land; some deny that in this state it has any injurious effect at all. This I fear is doubtful; we may infer, however, with some degree of probability, that it is from some property possessed by magnesia in the caustic state, and not possessed, or at least in an equal degree, either by *quick-lime* or by carbonate of magnesia, that its evil influence is *chiefly* to be ascribed.

3°. When exposed to the air, quick-lime speedily absorbs water and carbonic acid from the air, forming first a *hydrate** in fine powder, and then a carbonate. Caustic magnesia absorbs both of these more slowly than lime does, and in the presence of the latter, or when mixed with it, must absorb them more slowly still, since the lime will seize on the greater portion of the moisture and carbonic acid which exists in the air, immediately surrounding both. When slaked in the air also, the lime may be transformed in great part into carbonate, while the magnesia still remains in the state of hydrate, and it is a property of this hydrate to attract carbonic acid more feebly and slowly, even than the newly burned magnesia as it comes from the kiln. Hence when buried in the soil, after the lime has become nearly all transformed into carbonate, the magnesia may still be all either in the dry caustic state, or in that of a hydrate only.

4°. Now there exist in the soil, and probably are exuded from the living roots, various *acid* substances, both of organic and of inorganic origin, which it is one of the functions of lime, when applied to the land, to combine with and render innoxious. But these acid compounds unite rather with the caustic magnesia, than with the lime which is already in combination with carbonic acid—and form *salts*,† which generally are *much more soluble in water* than the compounds of lime with the same acids. Hence the water that goes to the roots reaches them more or less loaded with magnesian salts, and carries into the vegetable circulation more magnesia than is consistent with the healthy growth of the plant.

It is hazardous to reason from the phenomena of animal to those of

* Compounds of substances with water are called *hydrates* (from the Greek word for water.) Thus slaked lime, a compound of lime with water, is called *hydrate of lime*—and the native compound of magnesia with water, alluded to in the text, is called *hydrate of magnesia*.

† Compounds of the *bases*,—potash, soda, lime, magnesia, &c.,—with *acids*,—sulphuric, muriatic, nitric, acetic (or vinegar), &c.,—are called *salts*.

vegetable physiology, yet if lime and magnesia have the power of differently affecting the animal economy, why may they not also very differently affect the vegetable economy? And since in the same circumstances, and in combination with the substances they meet with in the same soils, magnesia is capable of entering more largely into a plant by its roots—may not magnesia be considered capable of poisoning a plant, when lime in the same condition would only improve the soil?

I have said that it may be doubted whether magnesia in the state of carbonate is wholly unhurtful to the land. This doubt rests on the fact that the magnesia *retains* its carbonic acid more feebly than lime does —and therefore its carbonate is the more easily decomposed when an acid body comes in contact with both. Though, therefore, the magnesian carbonate will not lay hold of all acid matter so readily and surely as caustic magnesia may, still occasions may occur where acid matters being abundant in the soil, so much carbonate of magnesia may be decomposed and dissolved as to render the water absorbed by its roots destructive to the health or life of a plant.

In reference to this point, however, it must be distinctly understood, that magnesia is one of the kinds of inorganic food most necessary to plants, that a certain quantity of it in the soil is absolutely necessary to the growth of nearly all cultivated plants, and that it is only when it is conveyed to the roots in too large a quantity, that it proves injurious to vegetable life.

5°. *Magnesium* is the metallic basis of magnesia. Little is known of its properties, owing to the difficulty of preparing it in any considerable quantity for the purpose of experiment. It is a white metal, which, when heated in the air, takes fire and burns, combining with the oxygen of the atmosphere, and forming magnesia. It is not known to occur in nature in an elementary form, and therefore is not supposed directly to influence vegetation.

6°. *Chloride of Magnesium.*—When calcined or carbonated magnesia is dissolved in muriatic acid, and the solution evaporated to dryness, a white mass is obtained which is a *chloride of magnesium*, consisting of magnesium and chlorine only. This compound occurs not unfrequently in the soil, associated with chloride of calcium. It is met with also in the ash of plants, while in sea water, and in that of some salt lakes, it exists in very considerable quantity. Thus 100 parts of the water of the Atlantic have been found to contain 3½ of chloride of magnesium, while that of the Dead Sea yields about 24 parts of this compound.* Hence it is present in great abundance in the mother liquor of the salt pans, and it is from the refuse chloride in this liquor that the magnesia of the shops, as above stated, is frequently prepared.

The chloride of magnesium has not hitherto been made the subject of direct experiment as a fertilizer of the land. From the fact, however, that plants require much magnesia and some chlorine, there is reason to believe that, if cautiously applied, it might prove beneficial in some soils, and especially to grain crops. Its extreme solubility in water, however, suggests the use of caution in its application. The safest method is to

* 100 parts of the water of the Dead Sea contain also about 10½ of chloride of calcium, and nearly 8 of common salt.

dissolve it in a large quantity of water, and to apply it to the young plant by means of a water-cart. In this way the refuse of the salt works might, in some localities, be made available to useful purposes.

The chloride of magnesium is decomposed both by quick-lime and by carbonate of lime; hence when applied to a soil containing lime in either of these states, chloride of calcium and caustic or carbonated magnesia will be produced.

7°. *Nitrate of Magnesia* is formed by dissolving carbonate of magnesia in nitric acid, and evaporating the solution. It attracts moisture from the air with great rapidity, and runs into a liquid. It is probably formed naturally in soils containing magnesia, in the same way as nitrate of lime is known to be produced in soils containing lime. [See Lecture VIII., p. 159.] No direct experiments have yet been made as to its effects upon vegetation; but there can be no doubt that it would prove highly beneficial, could it be procured at a sufficiently cheap rate to admit of its economical application to the land.

8°. *Sulphate of Magnesia*—the common Epsom salts of the shops—is formed by dissolving carbonate of magnesia in diluted sulphuric acid. It exists in nearly all soils which are formed from, or are situated in, the neighbourhood of rocks containing magnesia. In some soils it is so abundant that in dry weather it forms a white efflorescence on the surface. This has been observed to take place in Bohemia, Hungary, and parts of Germany, and it may be frequently seen in warm summer weather in the neighbourhood of Durham.*

This salt has been found by Sprengel to act upon vegetation precisely in the same way as gypsum does, and on the same kind of plants. It must be used, however, in smaller quantity, owing to its great solubility. Its higher price will prevent its ever being *substituted* for gypsum, as a top-dressing for clover, &c., but it is worth the trial, whether corn plants, the grain of which contains much magnesia, might not be benefitted by the application of a small quantity of this sulphate—along with such other substances as are capable of yielding the remaining constituents which compose the inorganic matter of the grain. Its price is not too high to admit of this more restricted application.†

9°. *Phosphate of Magnesia.*—Magnesia exists in combination with phosphoric acid, in the solids and fluids of all animals, though not so abundantly as the phosphates of lime. In most soils phosphate of magnesia is probable present in minute quantity, since in the ashes of some varieties of grain it is found in very considerable proportion.

Its action upon vegetation has never been tried directly, but as it exists in urine, and in most animal manures, a portion of their efficacy may be due to its presence. In turf ashes, which often prove a valuable manure, it is sometimes met with in appreciable quantity, and their beneficial operation in such cases has been attributed in part to the agency of this phosphate.

* It occasionally collects beneath the plaster of old walls in Durham. In one of the lower rooms of the old Exchequer buildings, I found it forming an extensive layer nearly half an inch thick, beneath the damp plaster. The magnesia is derived from the magnesian limestone, used both for mortar and for building stone.

† Its price in Newcastle in the state of crystals, is about 10s. a cwt. The impure salt collected at the alum works on the Yorkshire coast, might be obtained, I should suppose, for little more than half this price.

IX.—ALUMINIUM, ALUMINA, SULPHATE AND PHOSPHATE OF ALUMINA—ALUM.

1°. *Aluminium* is another of those rare and little known metals, the existence of which was established by Sir H. Davy. In combination with oxygen it forms *alumina*, and in this state it exists in such abundance in nature, as to form a large portion of the entire crust of the globe.

2°. *Alumina, the earth of Alum.*—When common alum is dissolved in water, and a solution of carbonate of soda or of ammonia is added to it, a bulky white powder falls, which, when collected on a filter, well washed and dried, is nearly pure alumina. This substance occurs on the surface of the earth in a pure state only in some rare minerals, such as the corundum, the sapphire, and the ruby,—but it constitutes a large proportion of all the slaty and shaley rocks. It is the principal ingredient also of all clays (pipe-clay for example) and clayey soils, which increase in tenacity in proportion to the quantity of alumina they contain.

When pure, it is a white tasteless earthy substance, which adheres to the tongue, has a density of 2·00, and is insoluble in water, but dissolves readily in caustic potash and soda and in most acids, at least when newly thrown down from a solution of alum. When heated to redness, however, it becomes hard and dense, as in burned clay and fire bricks, and can then only be dissolved with extreme difficulty, even by the strongest acids. Though it exists so largely in the soil, it contributes but little in a direct manner to the *nourishment* of plants. The ash they leave contains in general but a very small per-centage of alumina, as will more clearly appear hereafter,—the principal agency, therefore, of this ingredient of the soil is most probably of an indirect, perhaps of a mechanical kind.

It has been stated in a preceding Lecture (p. 23), that charcoal has the property of absorbing gaseous substances, such as ammonia, from the atmosphere, and that the action of charcoal powder, in promoting vegetation, has been in a great measure ascribed to this property. The same property, we have also seen (p. 136), is ascribed to gypsum, and hence its fertilizing action has been explained in a similar way. Alumina is said to be equally absorbent of ammonia; and the use of burned clay as a top-dressing, so strongly recommended by General Beatson, [*New System of Cultivation*, London, 1820,] is ascribed to its power of abstracting ammonia from the air, and fixing it in the soil ready to be conveyed by the rains to the roots of the plants that grow upon it [Liebig, p. 90.] It has been already shown (p. 136,) that this mode of accounting for the action of gypsum is not satisfactory as a *sole* cause—in the case of alumina, the fact of its absorbing ammonia is hypothetical,* and therefore the explanation founded upon this fact is not to be implicitly relied upon.

3°. *Sulphate of Alumina.*—When alumina is digested in diluted sul-

* Because clays of many varieties—pipe-clay for example—contain traces of ammonia, which they evolve when moistened with a solution of caustic potash,—it is inferred that they have absorbed this ammonia from the atmosphere. The same inference is drawn from the fact of its presence in oxide of iron.—[Liebig's *Organic Chemistry applied to Agriculture*, p. 89.]—In neither case does the inference appear to me to be *necessary*. Much of the ammonia may have been formed in the soil, during the oxidation of the iron itself, or during the decay of vegetable and animal substances.—See above, Lecture VIII., p. 158.

phuric acid, it readily dissolves, and forms a solution of sulphate of alumina. This solution is characterized by a remarkable and almost peculiar sweetish astringent taste. When evaporated to dryness it yields a white salt, which dissolves in twice its weight of water only, and when exposed to the air, attracts moisture rapidly, and spontaneously runs to a liquid. This salt exists in some soils, especially in those of wet, marshy, and peaty lands.

No experiments have yet been made with the view of determining its direct influence upon vegetation.

4°. *Phosphates of Alumina.*—In combination with phosphoric acid, alumina forms one compound well known to mineralogists, by the name of *wavellite*. This mineral, however, occurs in too small quantity to be an object of interest to the agriculturist.

Phosphoric acid is disseminated in some form or other throughout our clayey soils, though in very small and variable quantity. It is most probable that in these soils a portion of the acid at least is in combination with the alumina in the state of phosphate. One of the most difficult problems in analytical chemistry is to effect a perfect separation of a small proportion of phosphoric acid from alumina, and rigorously to estimate its quantity; hence in the greater part of the analyses of soils hitherto published, this most important ingredient in a fertile soil (the phosphoric acid), when in combination with, or in presence of alumina, has either been altogether neglected, or rudely guessed at, or indicated by a rough approximation only. We have no direct proof, therefore, of the extent to which the phosphates of alumina exist in different soils.

5°. *Alum.*—The common alum of the shops owes its well known sweetish astringent taste to the presence of the above sulphate of alumina. It consists in 100 parts of about 40 of sulphate of alumina, 14½ of potash, [described p. 189,] and 45½ of water. Alum is formed naturally on many parts of the earth's surface, especially as an efflorescence on certain soils, and on some rocks when exposed to the air,—as on the alum shales of the Yorkshire coast. It is largely manufactured by calcining, and afterwards washing these alum shales.

Alum has not been extensively tried as a manure. Its composition, however, would lead us to expect it to exert a beneficial influence on the growth of many plants—while the price, especially of the less pure varieties, is such as to admit of its being applied to the land at a comparatively small cost. From some experiments made on a small scale, Sprengel considers it highly worthy the attention of the practical agriculturist.

X.—SILICA, SILICON, SILICATES OF POTASH, OF SODA, OF LIME, OF MAGNESIA, AND OF ALUMINA.

1°. *Silica.*—The chief ingredient in all sand-stones and in nearly all sands and sandy soils, is known to chemists by the name of silica. Flints are nearly pure silex or silica—common quartz rock is another form of the same substance—while the colourless and more or less transparent varieties of rock crystal and chalcedony present it in a state of almost perfect purity. It exists abundantly in almost all soils, constituting what is called their *siliceous* portion, and is found in the ashes of all plants without exception, but especially in those of the grasses. Silica

is without colour, taste, or smell, and cannot be melted by the strongest heat. As it occurs in the mineral kingdom—in the state of flint, of quartz, or of sand—it is perfectly insoluble in pure water, either cold or hot, does not dissolve in acid and very slowly in alkaline solutions. When mixed with potash, soda, or lime, and heated in a crucible to a high temperature, it melts and forms a glass. *Window* and *plate* glass consists chiefly of silica, lime, and soda, *flint* glass contains litharge [oxide of lead] in place of the lime. But though the various forms of more or less pure silica, which are met with in the mineral kingdom, are absolutely insoluble in water, yet it sometimes occurs in nature, and can readily be prepared in a state in which pure water, and even acid solutions, will take it up in considerable quantity. In this state it may be obtained by reducing crown-glass to a fine powder, and digesting it in strong muriatic acid, or by melting quartz sand in a large quantity of potash or soda, and afterwards treating the glass that is formed with diluted muriatic acid.

Silica is one of the most abundant substances in nature, and in combination with potash, soda, lime, magnesia, and alumina, it forms a large portion of all the so-called crystalline (granitic, basaltic, &c.) rocks. The compounds of silica, with these bases, are called *silicates*. By the action of the air, and other causes, these silicates undergo decomposition, as glass does when digested with muriatic acid, and the silica is separated in the *soluble* state. Hence its presence in considerable quantity in the waters of many mineral and especially hot mineral springs, and in appreciable proportion in nearly all waters that rise from any considerable depth beneath the surface, or have made their way through any considerable extent of soil.

In the substance of living vegetables it exists, for the most part, in this state of combination—as well as in the form of an extremely delicate tissue, of which the fibres are exceedingly minute, and therefore expose a large surface to the action of any decomposing agent, or of any liquid capable of dissolving it. In the compost heaps these silicates undergo decomposition,—and the more readily the less they have been previously dried, or the greener they are,—and the silica of the plant is liberated in a soluble state. Whether or not, when thus liberated, it will be carried, *uncombined*, into the roots of the plants by the water they absorb, will depend upon the quantity of potash or soda in the compost or in the soil, and upon other circumstances hereafter to be explained.

2°. *Silicon* is known only in the state of a dark brown powder, which has not as yet been met with in nature in an elementary form, and is prepared by the chemist with considerable difficulty. When heated in the air, or in oxygen gas, it burns, combines with oxygen, and is converted into *silica*. Silica, therefore, in its various forms, is a compound of silicon with oxygen. It consists of 48 per cent. of the former and 52 per cent. of the latter.

3°. *Silicates of Potash and Soda.*—When finely powdered quartz, flint, or sand, is mixed with from one-half to three times its weight of dry carbonate of potash or soda, and exposed to a strong heat in a crucible, it readily unites with the potash or soda, and forms a glass. This glass is a *silicate* or a mixture of two or more *silicates* of potash or soda.

Silica combines with these *alkalies** in various proportions. If it be melted with much potash, the glass obtained will be readily soluble in water; if with little, the silicate which is formed will resist the action of water for any length of time. Window and plate-glass contain much silicate of potash or soda. A large quantity of alkali renders these varieties of glass more fusible and more easily worked, but at the same time makes them more susceptible of corrosion or tarnish by the action of the air.

The insoluble silicates of potash and soda exist also in many mineral substances. In the felspar and mica, of which granite in a great measure consists, they are present in considerable quantity. The former (felspar) contains one-third of its weight of an insoluble silicate of potash, consisting of nearly equal weights of potash and silica. In the variety called *albite* or *cleavelandite*, silicate of soda alone is found, while in some other varieties a mixture of both silicates is present. In mica from 12 to 20 per cent. of the same silicate of potash occurs, but soda can rarely be detected in this mineral. The trap-rocks also (whin, basalt, green-stone), so abundant in many parts of our island, consist almost entirely of *silicates*. Among these, however, the silicates of potash and soda rarely exceed 5 or 6 per cent. of the whole weight of the rock, and are often entirely absent.

These insoluble silicates also exist in the stems and leaves of nearly all plants. They are abundant in the stems of the grasses, especially in the straw of the cultivated grains, and form a large proportion of the ash which is left when these stems are burned [p. 178.]

It is important to the agriculturist to understand the relation which the carbonic acid of the atmosphere bears to these alkaline silicates which occur in the mineral and vegetable kingdom. Insoluble as they are in water, they are slowly decomposed by the united action of the moisture and carbonic acid of the air, the latter taking the potash or soda from the silica, and forming *carbonates* of these bases. In consequence of this decomposition the rock disintegrates and crumbles down, while the soluble carbonate is washed down by the rains or mists, and is borne to the lower grounds to enrich the alluvial and other soils, or is carried by the rivers to the sea.

In some cases, as in the softer felspar of some of the Cornish granites, this decomposition is comparatively rapid, in others, as in the Dartmoor and many of the Scottish granites, it is exceedingly slow,—but in all cases the rock crumbles to powder long before the whole of the silicates are decomposed, so that potash and soda are always present in greater or less quantity in granitic soils, and will continue to be separated from the decaying fragments of rock for an indefinite period of time.

But the silica of the felspar, or mica, or zeolitic† trap, when thus deprived of the potash with which it was combined, is in that peculiar state, in which, as above described [p. 206], it is capable of being dissolved in small quantity by pure water, and more largely by a solution of carbonate of potash or soda. Hence the same rains or mists which dis-

* Potash, soda, and ammonia are called *alkalies*; lime and magnesia are *alkaline earths*. See Lecture III., p. 51, *note*.

† The trap-rocks always more or less abound in *zeolitic* minerals, of which there is a great variety, and in which nearly all the alkali present in these (trap) rocks is contained.

solve the alkaline carbonates so slowly formed, take up also a portion of the silica, and convey it in a state of solution to the soils or to the rivers. Thus, with the exception of the dews and rains which fall directly from the heavens, few of the supplies of water by which plants are refreshed and fed, ever reach their roots entirely free from silica, in a form in which it can readily enter into their roots, and be appropriated to their nourishment.

In the farm-yard and the compost-heap, where vegetable matters are undergoing decomposition, the silicates they contain undergo similar decompositions, and, by similar chemical changes their silica is rendered soluble, and thus fitted, when mixed with the soil, again to minister to the wants and to aid the growth of new races of living vegetables.

4°. *Silicates of Lime.*—A mixture of sand or flint with quick-lime readily melts and forms a glassy silicate or a mixture of two or more silicates of lime. These silicates are also present in large quantity in window and plate-glass, and in some of the crystalline* (granite and trap) rocks. In felspar and mica, which abound, as we have seen, in the alkaline silicates, it is rare that any lime can be detected. In that variety of granite, however, to which the name of syenite is given by mineralogists, *hornblende* takes the place of *mica*, and some varieties of this hornblende contain from 20 to 35 per cent. of silicate of lime. This silicate (containing 38 per cent. of lime) is almost always present in the basaltic and trap-rocks, and sometimes, as in the augitic† traps, in a proportion much larger than that in which it exists in the unmixed hornblende. To this fact we shall have occasion to revert when we come to consider the relative fertility of different soils and the causes on which the difference of their several productive powers most probably depends.

Silicates of lime are also found in the ash, and probably‡ exist in the living stem and leaves of plants.

Like the similar compounds of potash and soda, the silicates of lime are slowly decomposed by the united agency of the moisture and the carbonic acid of the atmosphere. Carbonate of lime is formed, and silica is set at liberty. This carbonate of lime dissolves in the rains or dews which descend loaded with carbonic acid, [see page 46,] and the same waters take up also a portion of the soluble silica and diffuse both substances uniformly through the soil in which the decomposition takes place, or bear them from the higher grounds to the rivers and plains. The sparing but constant and long-continued supply of lime thus afforded to soils which rest upon decayed trap, or which are wholly made up of *rotten* rock, has a material influence upon their well-known agricultural capabilities.

5°. *Silicates of Magnesia.*—In combination with magnesia in different proportions, silica forms nearly the entire mass of those common minerals known by the names of serpentine and talc. In hornblende also and augite, silicates of magnesia exist in considerable quantity.

* So called because the minerals of which they consist are generally in a *crystallized* state.

† Rocks of which the mineral called *augite* forms a more or less considerable part.

‡ I say *probably*, because if uncombined silica be present in hay or straw along with carbonate or oxalate of lime, the heat employed in completely burning away the organic matter may be sufficient to cause the lime and silica to unite and form a silicate which will afterwards be found in the ash, though none previously existed in the stem.

They must, therefore, be present in greater or less quantity in soils which are *directly* formed from the decomposition of such rocks. Like the silicates of lime, however—though more slowly than these—they will undergo gradual decomposition by the action of the carbonic acid of the atmosphere, and of the acids produced in the soil by vegetation and by the decay of organic matter. The magnesia, like the lime, will thus be gradually brought down, in a state of solution (p. 200), from the higher grounds, or washed out of the soil, till at length it may wholly disappear from any given spot.*

6°. *Silicates of Alumina.*—Silica combines with alumina also in various proportions, forming silicates, which exist abundantly in nature in the crystalline rocks, and may also, like the other silicates, be formed by art. Felspar, mica, hornblende, and the augites, which abound in the trap-rocks, all contain much alumina in combination with silica, and we shall probably not be very far from the truth in assuming that upwards of one-half by weight of the trap-rocks in general—as well as of the hornblendes, micas, and felspars, of which so large a part of the granitic rocks is composed—consists of silicates of alumina. The alumina itself in these several minerals varies from 11 to 38 per cent., but generally averages about 20 per cent. of their entire weight.

These silicates, when they occur alone, unmixed or uncombined with other silicates, decompose very slowly by the action of the atmosphere. They disintegrate, however, and fall to powder, when the alkaline silicates with which they are associated in felspar, &c., are decomposed and removed by atmospheric causes. In this way the deposits of porcelain clay, so common in Cornwall and in other countries, have been produced from the disintegration of the felspathic rocks, and the clayey soils which occur in granite districts have not unfrequently had a similar origin.

When contained in the soil, the silicates of alumina undergo a slow decomposition from the action of the various acid substances to which they are exposed. A portion of their alumina is dissolved and separated by these acids, and in this soluble state is either conveyed to the roots of plants or is washed from the soil by the rains—or by the waters that arise from beneath.

The ash of plants contains only a very small proportion of alumina, yet even this small quantity they cannot derive from the silicates of this substance, since these are all insoluble in water—as alumina itself is. They obtain it, therefore, from some of those soluble compounds of alumina of which I have spoken as being either occasionally present (pp. 204-5), or as being naturally formed in the soil.

General remarks on these Silicates.—Of all these silicates it may be remarked in general—

1°. That besides existing in the minerals above-mentioned, and from which they are conveyed into the soil, they *are also slowly formed in the*

* I am indebted to Sir Charles Lemon for the analysis of a soil, on part of his own property, resting on serpentine, and bearing only *Erica vagans*, which illustrates the statement in the text. This soil consists of silica 70, alumina with a trace of gypsum 20, oxide of iron 6·2, and vegetable matter 3·8 per cent. If this soil has been formed from the rock on which it rests, the magnesia has been wholly washed out. Its constitution, however, points rather to a decayed felspar or slate rock, as the source from which it has been derived.

soil itself, when the ingredients of which they severally consist are naturally present in, or are artificially added to, the soil. Hence, the addition of potash or soda to the land may cause the production of silicates of these alkalies—probably soluble silicates—which water will be capable of dissolving and bearing to the extremities of the roots. Hence also, in a sandy soil, the addition of lime may give rise to the production of insoluble silicates of this earth,—and the beneficial effect of the lime upon the land may thus sooner cease to be observable than in soils of a different character, where it is not so liable to be locked up in an insoluble state of combination; and

2°. That with the exception of those of potash and soda, which contain much alkali, these silicates are all insoluble in water, and thus not directly available to the nutrition of plants. Except those of alumina, however, they are all slowly decomposed by atmospheric agents, and their constituent elements thus brought, to a certain extent, within the reach of plants; while, without exception, they are all capable of decomposition in the soil by the agency of the acid substances, chiefly organic, which there exist, or which are produced during the growth and decay of vegetable substances. From this latter source, the chief supply of the ingredients contained in the silicates, is, in most soils, derived by living plants.

To this cause is attributed the surprising effect often observed to follow from the addition of vegetable matter to a sandy soil on which a previous addition of lime had ceased to produce any further beneficial effect. The organic acids formed by the vegetable matter during its decay decompose the silicates of lime previously produced, and thus liberate the lime from its insoluble state of combination. But when the silicates have been all decomposed by this agency, the further addition of vegetable matter ceases necessarily to produce the same remarkable effects.

XI.—THE OXIDES, SULPHURETS, SULPHATES, AND CARBONATES OF IRON.

1°. *Oxides of Iron.*—It is well known that when metallic iron is exposed to moist air, it gradually rusts and becomes covered with, or wholly changed into, a crumbling ochrey mass of a reddish brown colour. This powder is a compound of iron and oxygen only, containing 69¼ per cent. of the former, and 30¾ per cent. of the latter.

When iron is heated in the smith's forge, and then beat on the anvil, a scale flies off which is of a black colour, and when crushed gives a black powder. This also consists of iron and oxygen only, but the proportion of oxygen is not so great as in the red powder above described. In both cases the iron has derived its oxygen from the atmosphere.

To these compounds of iron, with oxygen, the name of *oxides* is given. There are only two which are of interest to the agriculturist, namely,

	Consisting of Iron.	Oxygen.	Symbol.	Colour.
The *first* oxide* . .	77·23	22·77	Fe O†	Black
The *second* oxide .	69·34	30·66	Fe_2O_3	Red.

* The *first* is also called the *prot*-oxide, the *second* either the *sesqui*, or *more usually* the *per*-oxide of iron.

† Iron is represented by the symbol Fe, the initial letters of its Latin name (ferrum).

Both of these ex st abundantly in nature, and are present to a greater or less extent in all soils. The second or *per*-oxide, however, is by far the most abundant on the earth's surface, and the reddish colour observable in so many soils is principally due to the presence of this oxide.

The first oxide rarely occurs in the soil except in a state of combination with some acid substance,—and so strong is its tendency to combine with more oxygen, that when exposed to the air, even in a state of combination, it rapidly absorbs this element from the atmosphere and changes into per-oxide. This change is observable in all chalybeate springs, in which, as they rise to the surface, the iron is generally held in solution in the state of the first oxide. After a brief exposure to the air, more oxygen is absorbed, and a reddish pellicle is formed on the surface, which gradually falls and coats the channel along which the water runs, with a reddish sediment of insoluble per-oxide.

Both oxides are insoluble in pure water, and both dissolve in water containing acids in solution. The first oxide, however, dissolves in much greater quantity in the same weight of acid, and it is the compounds of this oxide which are usually present in the soil, and which, in boggy lands, prove so injurious to vegetation.*

The second oxide possesses two properties which, in connection with practical agriculture, are not void of some degree of importance.

1°. In a soil which contains much vegetable matter in a state of decay, the per-oxide is frequently deprived of one-third of its oxygen by the carbonaceous matter,† and is thus converted into the first oxide which readily dissolves in any of the acid substances with which it may be in contact. In this state of combination it is more or less soluble in water, and in some localities may be brought to the roots of plants in such quantity as to prove injurious to their growth.

2°. The red oxide of iron is said, like alumina (p. 197), to have the property of absorbing ammonia, and probably other gaseous substances and vapours, from the atmosphere and from the soil. In that which occurs in nature, either in the soil or near the surface of mineral veins, traces of ammonia can generally be detected. Since then ammonia is so beneficial—according to some so indispensably necessary—to vegetation, the property which the per-oxide of iron possesses of retaining this ammonia when it would otherwise escape from the soil, or of absorbing it from the atmosphere, and thus bringing it within the reach of plants, must also be indirectly favourable to vegetation—where the soil contains it in any considerable quantity.

An important practical precept is also to be drawn from these two properties of this oxide. A red irony soil, to which manure is added, should be frequently turned over, and should be kept loose and pervious to the air, in order that the formation of prot-oxide (first oxide) may be

* "That layer of soil (says Sprengel), is always especially rich in iron, over which the heel of the plough glides in preparing the land. The friction of the soil continually rubs off particles of iron, which absorb oxygen and change into the *first* oxide. Hence this part of the soil is always darker in colour than the rest; hence also the reason why the soil after deep ploughing, remains unproductive sometimes for several years."—*Chemie*, I., p. 428. While we admit that the presence of the first oxide of iron in the subsoil affects its fertility, when brought to the surface, we may doubt whether *much* of that iron can have been derived from the tear and wear of the plough.

† The carbon of the vegetable matter combines with the oxygen of the oxide to form *carbonic acid*.—See p. 53.

prevented as much as possible; and it may occasionally be summer-fallowed with advantage, in order also that the per-oxide may absorb from the air those volatile substances which are likely to prove beneficial to the growth of the future crops.

2°. *Sulphurets of Iron.*—Iron occurs in nature combined with sulphur in two proportions, forming a sulphuret and a *bi*-sulphuret. These consist respectively—

	Iron.	Sulphur.	Symbol.
The sulphuret . . .	62·77	37·23	$Fe\,S$
The bi-sulphuret of .	45·74	54·26	$Fe\,S_2$

and are both tasteless and insoluble in water.

1°. The first of these, the sulphuret ($Fe\,S$), occurs occasionally in boggy and marshy soils, in which salts of iron exist, or into which they are carried by rains or springs. It is not itself directly injurious to vegetation, but when exposed to the air it absorbs oxygen and forms *sulphate* of iron, which, when present in sufficient quantity, is eminently so.*

2°. The *bi-sulphuret*, or common iron pyrites ($Fe\,S_2$), is exceedingly abundant in nature. It occurs in nearly all rocky formations—and in most soils. It abounds in coal, and is the source of the sulphurous smell which many varieties emit while burning. It generally presents itself in masses of a yellow colour and metallic lustre, more or less perfectly crystallized in cubical forms, so brittle and hard as to strike fire with steel, and of a specific gravity four and a half times greater than that of water (Sp. gr. 4, 5). When heated in close vessels it parts with nearly one-half of its sulphur, and hence is often distilled for the sulphur it yields.

In the air it absorbs oxygen, in some cases—as in the waste coal heaps—with such rapidity as to heat, take fire, and burn. By this absorption of oxygen (oxidation), sulphuric acid and sulphate of iron are produced. In the alum shales the iron pyrites abounds, and these are often burned for the purpose of converting the sulphur and sulphuric acid for the subsequent manufacture of alum.

3°. *Sulphates of Iron.*—Of the sulphates of iron which are known, there is only one—the common *green vitriol* of the shops—that occurs in the soil in any considerable quantity. There are few soils, perhaps, in which its presence may not be detected, though it is in bogs and marshy places that it is most generally and most abundantly met with. It is often exceedingly injurious to vegetation in such localities, but it is decomposed by quick-lime, by chalk, and by all varieties of marl, and thus its noxious effects may in general be entirely prevented. To soils which abound in lime, it may even be applied with a beneficial effect.

When a solution of this salt is exposed to the air it speedily becomes covered with a pellicle of a yellow ochrey colour, which afterwards falls as a yellow sediment. This sediment consists of *per*-oxide of iron, containing a little sulphuric acid; but by the separation of this oxide the sulphuric acid is left in excess in the solution, which becomes sour, and

* Yet in small quantity it may be beneficial. Thus Sprengel mentions that the subsoil of a moor near Hanover, which contains some of this sulphuret of iron, produces astonishing effects when laid as a top-dressing on the grass lands. The explanation of this is, that the pyrites absorb oxygen and is converted into sulphate, and thus re-produces the remarkable effects observed on the addition of gypsum, of sulphuric acid, or of sulphate of soda, to similar grass lands.

still more injurious to vegetation than before. In boggy places the waters impregnated with iron are generally more or less in this acid state, and lime, chalk, and marl, with perfect drainage, are the only available means by which such lands can be sweetened and rendered fertile.

When iron pyrites is exposed to the air it slowly absorbs oxygen, and is converted into *sulphate* of iron and sulphuric acid; on the other hand, the sour solution above mentioned, when placed in contact with vegetable matter, where the air is excluded, parts with its oxygen to the decaying carbonaceous matter, and is again converted into iron pyrites. These two opposite processes are both continually in progress in nature, and often in the same locality,—the one on the surface, where air is present; the other in the subsoil, where the air is excluded.

4°. *Carbonates of Iron.*—When a solution of the sulphate of iron, above described, is mixed with one of carbonate of soda, a yellow powder falls, which is *carbonate of iron*. This carbonate is found abundantly in nature. It is the state in which the iron exists in the ore (clay-iron ore,) from which this metal is so largely extracted in our iron furnaces, and in the similar ore often found in the subsoil of boggy places, which is distinguished by the name of bog-iron ore.

Like the carbonate of lime, it is insoluble in water, but dissolves with considerable readiness in water charged with carbonic acid. In this state of solution it issues from the earth in most of our chalybeate springs, and it is owing to the escape of the excess of carbonic acid from the water, when it reaches the open air, that the yellow deposit of carbonate of iron more or less speedily falls.

The carbonate of iron, being insoluble in water, cannot be directly injurious to vegetation. When exposed to the air it gradually parts with its carbonic acid, and is converted into per-oxide of iron.

The ash of nearly all plants contains a more or less appreciable quantity of oxide of iron. This may have entered into the roots either in the state of soluble sulphate or of carbonate dissolved in carbonic acid, or of some other of those numerous soluble compounds of iron with *organic* acids, which may be expected to be occasionally present in the soil.

XII.—MANGANESE: OXIDES, CHLORIDES, CARBONATES, AND SULPHATES OF MANGANESE.

1°. *Manganese* is a metal which, in nature, is very frequently associated with iron in its various ores. It also resembles this metal in many of its properties. In the metallic state, however, it is not an object of manufacture, nor is it used for any purpose in the arts.

2°. *Oxides of Manganese.*—Manganese combines with oxygen in several proportions. The first oxide is of a light green colour, the second and third are black. The first is not known to occur in nature in an uncombined state, the two others exist abundantly in the common ores of manganese, and are extensively diffused, though in small quantity, through nearly all soils. They are all insoluble in water, but the two former dissolve in acids and form *salts*. Traces of these two oxides are also to be detected in the ash of nearly all plants.

3°. *Chloride, Carbonate, and Sulphate of Manganese.*—If any of

these oxides be dissolved in muriatic acid a solution of *chloride* of manganese will be obtained.

If this solution of chloride of manganese be mixed with one of carbonate of soda, a white insoluble powder will fall, which is *carbonate* of manganese.

If this carbonate be dissolved in diluted sulphuric acid, or if any of the oxides be digested in this acid, a solution of *sulphate* of manganese will be formed.

The carbonate of manganese, and its oxides, will also dissolve, though more slowly, in acetic acid (vinegar), and in other organic acids which may be present in the soil, and will form with them other soluble salts.

The compounds of manganese exist in plants in much less quantity than those of iron; but as its oxides, like those of iron, are insoluble in pure water, this metal most likely finds its way into the state of one or other of the soluble compounds above described.

§ 2. *Tabular view of the constitution of the compounds of the inorganic elements above described.*

Having in the preceding section briefly described the several compounds of the *inorganic elements of plants*, which either enter into the constitution of vegetable substances, or are supposed to minister to their growth—it may prove useful hereafter, if I exhibit at one view the composition per cent. of the various oxides, chlorides, sulphurets, and oxygen-acid salts,* to which I have had occasion to direct your attention.

We shall have occasion to refer to the numbers in the following tables in our subsequent calculations.

1°.—*Oxygen per cent. in the oxides of the inorganic elements.*

	Oxygen per cent.		Oxygen per cent.
Sulphurous Acid	49·85	Alumina	46·70
Sulphuric Acid	59·86	Silica	51·96
Phosphoric Acid	56·04	Prot-oxide of Iron	22·77
Potash	16·95	Per-oxide of Iron	30·66
Soda	25·58	Prot-oxide of Manganese	22·43
Lime	28·09	Sesqui-oxide do.	30·25
Magnesia	38·71	Per-oxide do.	36·64

2°.—*Chlorine or Sulphur per cent. in the chlorides and sulphurets.*

	Chlorine per cent.		Sulphur per cent.
Chloride of Potassium	47·47	Sulphuret of Potassium	29·11
——— Sodium	60·34	——— Sodium	40·88
——— Calcium	63·38	——— Calcium	44·00
——— Magnesium	73·65	——— Iron	37·23
First Chloride of Iron	56·62	Bi-Sulphuret of Iron, (Iron Pyrites)	47·08
Second do. do.	66·19		

* So called because the acid they contain has oxygen for one of its constituents.

3°.—*Composition per cent. of the Saline combinations above described.*

	Acid.	Base.	Water.
Carbonate of Potash	31·91	68·09	
Bi-carbonate of do.	48·38	51·62	
Sulphate of do.	45·93	54·07	
Nitrate of do.	53·44	46·56	
Binoxalate of do. (Salt of sorrel) .	52·64	34·29	13·07
Bitartrate of do. (Cream of tartar)	70·28	24·96	4·76
Phosphate of do.	43·06	56·94	
Bi-phosphate of do.	60·20	39·80	
Carbonate of Soda (dry)	41·42	58·58	
——— (crystallized) .	15·43	21·81	62·76
Bi-carbonate of Soda	58·58	41·42	
Nitrate of do.	63·40	36·60	
Sulphate of do. (dry) . .	56·18	43·82	
——— do. (crystallized) .	24·85	19·38	55·77
Phosphate of do.	53·30	46·70	
Bi-phosphate of do.	69·54	30·46	
Carbonate of Lime	43·71	56·29	
Sulphate of do. (Gypsum) . .	46·31	32·90	20·79
——— (burned) . .	58·47	41·53	
Nitrate of Lime	65·54	34·46	
Phosphate of Lime (Apatite) . .	45·52	54·48	
Bi-phosphate of Lime	71·48	28·52	
Earth of Bones	48·45	51·55	
Carbonate of Magnesia	51·69	48·31	
Bi-carbonate of do.	68·15	31·85	
Sulphate of do. (Epsom salts) .	32·40	16·70	50·90
Nitrate of do.	72·38	27·62	
Phosphate of do.	63·33	36·67	
Sulphate of Alumina	70·07	29·93	
Phosphate of do.	67·57	32·43	
Silicate of Potash (soluble) . .	49·46	50·54	
Bi-silicate of do. (do.) . .	66·19	33·81	
Silicate of Soda (do.) . .	59·63	40·37	
Bi-silicate of do. (do.) . .	74·71	25·29	
Silicate of Lime	61·85	38·15	
——— Magnesia	69·08	30·92	
——— Alumina	72·95	27·05	
Carbonate of Iron	38·63	61·37	
Sulphate of do. (crystallized) .	31·03	27·19	41·78
Carbonate of Manganese	38·27	61·73	
Sulphate of do. (crystallized)	33·20	29·54	37·26

§ 3. *On the relative proportions of the different inorganic compounds present in the ash of plants.*

Having thus made you acquainted with the general properties and composition of the several compound substances of which the ash of plants consists, we now advance to the consideration of the *relative proportions* in which these substances exist in the ash of the different kinds of plants usually cultivated for food.

We have seen (p. 178) that different species of plants leave very different quantities of ash when burned;—the ash left by different species contains also the above earthy and saline substances in very unlike proportions. This fact has already been stated generally (p. 180); we are now to illustrate it more fully, and to show the important practical deductions to which it leads.

I.—OF THE ASH OF WHEAT.

According to the analysis of Sprengel, 1000 lbs. of wheat leave 11·77 lbs., and of wheat straw 35·18 lbs. of ash, consisting of—

	Grain of Wheat.	Straw of Wheat.
Potash	2·25 lbs.	0·20 lbs.
Soda	2·40	0·29
Lime	0·96	2·40
Magnesia	0·90	0·32
Alumina, with a trace of Iron	0·26	0·90
Silica	4·00	28·70
Sulphuric Acid	0·50	0·37
Phosphoric Acid	0·40	1·70
Chlorine	0·10	0·30
	11·77 lbs.	35·18 lbs.

If the produce of a field be at the rate per acre of 25 bushels of wheat, each 60 lbs., and if the straw* be equal to twice the weight of the grain, the quantity of each reaped per acre will be

Grain . . . 1500 lbs. } from a produce of 25 bushels;
Straw . . . 3000 lbs. }

so that the quantity of the different inorganic compounds carried off *from the soil of each acre* will be, in the grain ½ more than is represented in the second column, and in the straw 3 times as much as is represented in the third column.

II.—OF THE ASH OF BARLEY.

A thousand pounds of the grain of barley (two-rowed, *hordeum distichon*,) leave 23½ lbs., and of the ripe dry straw 52·42 lbs. of ash. This ash consists of—

* The proportion of the straw to the seed in grain of all kinds is very variable. In wheat it is said to average twice the weight of the grain, but it is very often, even in heavy crops, 3 to 3½ times that weight.

	Grain.	Straw.
Potash	2·78 lbs.	1·80 lbs.
Soda	2·90	0·48
Lime	1·06	5·54
Magnesia	1·80	0·76
Alumina	0·25	1·46
Oxide of Iron	a trace.	0·14
Oxide of Manganese	—	0·20
Silica	11·82	38·56
Sulphuric Acid	0·59	1·18
Phosphoric Acid	2·10	1·60
Chlorine	0·19	0·70
	23·49 lbs.	52·42 lbs.

If the produce of a crop of barley amount to 38 bushels of 63 lbs. each per acre, and the straw exceed the grain in weight one-sixth, the weight of each reaped per acre will be about

2000 lbs. of grain, } from a produce of 38 bushels;
2300 lbs. of straw, }

and the inorganic matters carried off from the soil by each will be obtained by multiplying those contained in the second column (above) by 2, and in the third by $2\frac{1}{3}$.

III.—OF THE ASH OF OATS.

In 1000 lbs. of the grain of the oat are contained about 26 lbs., and of the dry straw about $57\frac{1}{2}$ lbs. of inorganic matter, consisting of—

	Grain.	Straw.
Potash	1·50 lbs.	8·70 lbs.
Soda	1·32	0·02
Lime	0·86	1·52
Magnesia	0·67	0·22
Alumina	0·14	0·06
Oxide of Iron	0·40	0·02
Oxide of Manganese	0·00	0·02
Silica	19·76	45·88
Sulphuric Acid	0 35	0·79
Phosphoric Acid	0·70	0·12
Chlorine	0·10	0·05
	25·80 lbs.	57·40 lbs.

If an acre of land yield 50 bushels, each 54 lbs., of oats, and two-thirds* more in weight of straw, there will be reaped per acre,

Of grain 2250 lbs., } from a produce of 50 bushels;
Of straw 3750 lbs., }

and the weight of the inorganic matters carried off will be equal to $2\frac{1}{2}$ times the quantities contained in the second column, and $3\frac{3}{4}$ times those contained in the third column.

* Of all kinds of grain, the oat gives the most variable proportion of straw, that which is obtained at one time, and in one locality, being two or three times greater than that reaped in another.

IV.—OF THE ASH OF RYE.

The weight of ash contained in 1000 lbs. of the grain of rye is 10½ lbs., and of the straw 28 lbs. This ash consists of

	Grain.	Straw.
Potash } Soda }	5·32 lbs.	0·32 lbs. 0·11
Lime	1·22	1·78
Magnesia	1·78	0·12
Alumina } Oxide of Iron }	0·24 0·42	0·25
Oxide of Manganese	0·34	—
Silica	1·64	22·97
Sulphuric Acid	0·23	1·70
Phosphoric Acid	0·46	0·51
Chlorine	0·09	0·17
	10·40 lbs.	27·93 lbs.

Rye is remarkable for the quantity of straw it yields, which is often from 3 to 4 times the weight of the grain. The return in grain reaches about the same average as that of wheat. From an acre of land yielding a crop of 25 bushels, each 54 lbs., there would be reaped

Of grain 1350 lbs.; of straw 4000 lbs.;

the whole weight of inorganic matters contained in which is equal to ⅛ more than is represented in the second column, added to 4 times the weights contained in the third column.

V.—OF THE ASH OF BEANS, PEAS, AND VETCHES.

The ash of the seed and straw of the field bean, the field pea, and the common vetch (*vicia sativa*,) dried in the air, contains in 1000 lbs. the several inorganic compounds in the following proportions:

	FIELD BEAN.		FIELD PEA.		COMMON VETCH.	
	Seed.	Straw.	Seed.	Straw.	Seed.	Straw.
Potash	4·15	16·56	8·10	2·35	8·97	18·10
Soda	8·16	0·50	7·39	—	6·22	0·52
Lime	1·65	6·24	0·58	27·30	1·60	19·55
Magnesia	1·58	2·09	1·36	3·42	1·42	3·24
Alumina	0·34	0·10	0·20	0·60	0·22	0·15
Oxide of Iron	—	0·07	0·10	0·20	0·09	0·09
Oxide of Manganese	—	0·05	—	0·07	0·05	0·08
Silica	1·26	2·20	4·10	9·96	2·00	4·42
Sulphuric Acid	0·89	0·34	0·53	3·37	0·50	1·22
Phosphoric Acid	2·92	2·26	1·90	2·40	1·40	2·80
Chlorine	0·41	0·80	0·38	0·04	0·43	0·84
	21·36	31·21	24·64	49·71	22·90	51·01

On comparing the numbers in these columns, we cannot fail to remark,—

1°. How much potash there is in the straw of the bean and the vetch.

2°. That while there is only a trace of soda in any of the three straws, there is a considerable quantity in all the seeds.

3°. How large a proportion of lime exists in the *straw* of the pea and of the vetch—compared with that of the bean—and how much larger the proportion is in all the straws than in any of the grains—and

4°. That the quantity of silica in pea straw is double of what is contained in the straw of the vetch, and 4 times that of the bean straw.

The produce of straw from these three varieties of pulse is very bulky, but varies in weight from 1 to 1¾ tons—or is on an average about 2300 lbs. per acre. The produce of grain is still more variable.

The bean gives from	16 to 40 bushels,	of about	63 lbs.
The pea . .	12 to 84 "	"	64 lbs.
The vetch . .	16 to 40 "	"	66 lbs.

The mean return from beans is estimated by Schwertz [*Anleitung Zum Praktischen Ackerbau*, II., p. 346,] at 25 bushels (1600 lbs.), from peas at 15 bushels (1000 lbs.), and from vetches at 17 bushels (1100 lbs.) per acre.

The quantity of the several inorganic matters, therefore, carried off from an acre in the straw of these crops, will be about 2½ times the weights given in the table—and in the grains, where the crop is near the above average, 1¾ times the weights in the tables for beans and for peas, and for vetches very nearly the actual weights above given.

VI.—OF THE ASH OF THE TURNIP, CARROT, PARSNIP, AND POTATO.

These four roots, as they are carried from the field, contain respectively in ten thousand pounds—

	TURNIP.		CARROT.	PARSNIP.	POTATO.	
	Roots.	Leaves.			Roots.	Tops.
Potash . . .	23·86	32·3	35·33	20·79	40·28	81·9
Soda	10·48	22·2	9·22	7·02	23·34	0·9
Lime	7·52	62·0	6·57	4·68	3·31	129·7
Magnesia . . .	2·54	5·9	3·84	2·70	3·24	17·0
Alumina . . .	0·36	0·3	0·39	0·24	0·50	0·4
Oxide of Iron . .	0·32	1·7	0·33	0·05	0·32	0·2
Oxide of Manganese	—	—	0·60	—	—	—
Silica	3·88	12·8	1·37	1·62	0·84	49·4
Sulphuric Acid .	8·01	25·2	2·70	1·92	5·40	4·2
Phosphoric Acid .	3·67	9·8	5·14	1·00	4·01	19·7
Chlorine . . .	2·39	8·7	0·70	1·78	1·60	5·0
	63·03	180·9	66·19	41·80	82·83	308·4

These roots, as already stated (note, p. 178), contain very much water, so that, in a dry state, the *proportion* of inorganic matter present in them is very much greater than is represented by the above numbers. I have, however, given the quantities contained in the crop as it is carried from the field, as alone likely to be of practical utility.

The crops of these several roots vary very much in different localities, being in some places twice and even thrice as much as in others—every nine tons, however, which are carried off the ground, contain about twice the weight of saline and earthy matters indicated by the numbers in the table.

VII.—OF THE ASH OF THE GRASSES AND CLOVERS.

The following table might have been much enlarged. I have thought it necessary, however, to introduce in this place only those species of grass and clover which are in most extensive use. I have also calculated the weights given below, for these plants in the *state of hay only*, as the succulency of the grasses,—that is, the quantity of water contained in the green crop,—varies so much that no correct estimate could be made of the quantity of inorganic matter present in hay or grass, from a knowledge of its weight in the green state only:

	Rye Grass Hay.	Red Clover.	White Clover.	Lucerne.	Sainfoin.
Potash	8·81	19·95	31·05	13·40	20·57
Soda	3·94	5·29	5·79	6·15	4·37
Lime	7·34	27·80	23·48	48·31	21·95
Magnesia . . .	0·90	3·33	3·05	3·48	2·88
Alumina . . .	0·31	0·14	1·90	0·30	0·66
Oxide of Iron . .	—	—	0·63	0·30	—
Oxide of Manganese	—	—	—	—	—
Silica	27·72	3·61	14·73	3·30	5·00
Sulphuric acid . .	3·53	4·47	3·53	4·04	3·41
Phosphoric acid .	0·25	6·57	5·05	13·07	9·16
Chlorine	0·06	3·62	2·11	3·18	1·57 ?
	52·86	74·78	91·32	95·53	69·57

The above quantities are contained in a thousand pounds of the dry hay of each plant.

On comparing the numbers opposite to potash, lime, magnesia, alumina, silica, and phosphoric acid, we see very striking differences in the quantities of these substances contained in equal weights of the above different kinds of hay. These differences lead to very important practical inferences in reference,—

1°. To the kind of soil in which each will grow most luxuriantly.

2°. To the artificial means by which the growth of each may be promoted—in so far as this growth depends upon the supply of inorganic food to the growing plant.

3°. To the feeding properties of each, and to the *kind* of stock they are severally most fitted to nourish.

To these and other important practical deductions suggested by the above tabulated analyses—as well as by those previously given—of the inorganic matters contained in the several varieties of vegetable productions usually raised for food, we shall hereafter have frequent occasion to revert. In the mean time, a preliminary inquiry demands our attention, which we shall proceed to consider in the following section.

§ 4. *To what extent do the crops most usually cultivated, exhaust the soil of inorganic vegetable food?*

A bare inspection of the tabular results exhibited in the preceding section gives but a faint idea of the extent to which the inorganic elementary bodies are necessarily withdrawn from the soil in the ordinary course of cropping.

I. Let us consider the effect upon the soil of a still too common three years' course of cropping—*fallow, wheat, oats.** If the produce of such a course be 25 bushels of wheat and 50 bushels of oats, there would be carried from the soil every three years in pounds—

	WHEAT.		OATS.		Total.
	Grain.	Straw.	Grain.	Straw.	
Potash	3·3	0·6	3·75	32·7	40·35
Soda	3·5	0·9	3·3	—	7·7
Lime	1·5	7·2	2·5	5·7	16·9
Magnesia	1·5	1·0	1·7	0·8	5·0
Oxide of Iron . .	—	—	1·0	—	1·0
Silica	6·0	86·0	50·0	172·0	314·0
Sulphuric Acid . .	0·75	1·0	0·9	3·0	5·65
Phosphoric Acid .	0·6	5·0	1·43	0·5	7·53
					398·13

The gross weight carried off in these crops is large—amounting to about 400 lbs. It will vary, however, with the kind of wheat and oats which are grown, and may often be greater than this.—[See the following section (§ 5) of the present Lecture.] The greatest portion of the matter carried off, however—upwards of three-fourths of the whole—consists of silica; the rest of the materials are equal to

60 lbs. of dry pearl-ash,
36 lbs. of the common soda of the shops,
28 lbs. of bone-dust,
12 lbs. of gypsum,
5 lbs. of quick-lime,
5 lbs. of magnesia,—or for the last three may be substituted 33 lbs. of common Epsom salts and 17 lbs. of quick-lime.

The form in which the silica may be restored to the soil in a state in which the plant can absorb it, will be considered hereafter.

Though large as a whole, the weight of each of the ingredients, taken singly, is not great; and yet it is not difficult to understand that if a constant drain be kept up on the soil year after year, and the practical farming adopted is of such a kind as *not* to restore to the soil a due proportion of *each* of the substances carried off—the time must come when, under ordinary circumstances, the soil will no longer be able to supply the demands of a healthy and luxuriant vegetation.

II. Let us next consider the effect of a four-years' course system in withdrawing these inorganic substances from the soil. And for this purpose let us adopt one suited to the lighter soils—as to that of Norfolk—*turnips, barley, clover and rye grass, wheat.*

Let the crop of turnips amount to 25 tons of roots per acre, of barley to 38 bushels, of clover and rye grass each to one ton of hay, and of wheat as before to 25 bushels. Then we have from the entire rotation in pounds—

* Common, among other counties, in that of Durham. There are cases, however, in which this three years' course may not be indefensible, and it never could be compared with some of the so-called *improved* rotations in East Lothian in the time of Lord Kames; as for instance, *fallow, barley, clover*, manure on the clover stubble, then *wheat, barley, oats.*—See *The Gentleman Farmer* (1802), p. 147.

	Turnip Roots.	Barley. Grain.	Barley. Straw.	Red Clover.	Rye Grass.	Wheat. Grain.	Wheat. Straw.	Total.
Potash	145·5	5·6	4·5	45·0	28·5	3·3	0·6	233·0
Soda	64·3	5·8	1·1	12·0	9·0	3·5	0·9	96·6
Lime	45·8	2·1	12·9	63·0	16·5	1·5	7·2	149·0
Magnesia	15·5	3·6	1·8	7·5	2·0	1·5	1·0	32·9
Alumina	2·2	0·5	3·4	0·3	0·8	0·4	2·7	10·3
Silica	23·6	23·6	90·0	8·0	62·0	6·0	86·0	299·2
Sulphuric Acid	49·0	1·2	2·8	10·0	8·0	0·8	1·0	72·8
Phosphoric do.	22·4	4·2	3·7	15·0	0·6	0·6	5·0	51·5
Chlorine	14·5	0·4	1·5	8·0	0·1	0·2	0·9	25 6
								970·9*

On comparing the numbers in the last column—containing the total quantity of matter abstracted—with those contained in the three years' rotation (p. 221), we see how very much larger an addition must be made to the land every fourth year, if we are to restore to it any thing like an equivalent for the inorganic matter carried off.

It will be especially observed that the quantity of potash, and of soda, and indeed of nearly every ingredient except the silica, carried off in this course of cropping, is much greater, even in proportion to the time it occupies, than in the three-year shift—and that *nine-tenths of the potash and soda withdrawn from the soil are contained in the green crops.*

To place the relative effect of the green and corn crops upon the soil in a clearer light, I shall exhibit the several quantities of common and *artificial* salts and manures which it would be necessary to add to each acre at the beginning of this rotation, in order to supply the various inorganic substances about to be taken from the land in the next four years' cropping. These quantities are as follow, in pounds:—

	Total.	For the Green Crops.	For the Corn Crops.
Dry Pearl-ash	325	316	9
Crystallized Carbonate of Soda†	333	290	43
Common Salt	43	38	5
Gypsum	—	30	—
Quick-lime	150	100	7
Epsom Salts	200	150	50
Alum	83	27	56
Bone-dust	210	150	60

With the exception of the silica, the substances above-named, in the quantities given, will replace all the inorganic matters contained in the whole crop reared, the turnip tops alone not included. A single glance at the second and third columns shows how much greater a proportion of all these substances is necessary to return what the green crops have taken from the land.

That the fertility of the soil depends in some considerable degree on

* This is exclusive of the turnip tops, which I have omitted, from not knowing what proportion their weight in the green state generally bears to that of the roots.

† Or for every 100 lbs. of the common carbonate of soda may be substituted 40 lbs. of common salt or 60 lbs. of dry nitrate of soda.

the quantity of the alkaline and other compounds present in it, there can be no question,—since not only do we find extraordinary natural luxuriance of vegetation where some of these happen to be present in the soil, but we can often greatly increase the apparent productiveness of our fields by spreading such substances over them in sufficient quantity.

How comes it, then, that the green crops which carry off all these substances in the greatest quantity by very much, should yet least injure the land,—nay, should rather renew and prepare it again for the growth of crops of corn?

This is one of the most interesting practical questions which can present itself to us in the existing state of theoretical agriculture;—but it would carry us away from our more immediate object, were we prematurely to enter upon the discussion of it in this place. It will hereafter demand our especial attention, when we shall have become familiar with the nature and origin of soils.

I may be permitted, however, to draw your attention here for a moment—as neither out of place, nor uninteresting, for many reasons,—to an opinion expressed by Liebig on the question *why wheat prefers stiff and clayey soils.* "Again," he says, "how does it happen that wheat does not flourish in a sandy soil, and that a calcareous soil is also unsuitable for its growth, unless it be mixed with a considerable quantity of clay? It is because these soils do not contain alkalies in sufficient quantity, the growth of wheat being arrested by this circumstance, even should all other substances be presented in abundance."—[*Organic Chemistry applied to Agriculture*, p. 151.]

Without dwelling on the fact that excellent crops of wheat are reaped in some parts of our island from sandy and calcareous* soils—what kind of crops, we may ask, can be reared with success on the lighter soils to which wheat seems least adapted? The turnip rejoices in light land, and the potato not unfrequently attains the greatest perfection on a sandy soil. Yet ten tons of potato roots, or twenty of turnip bulbs,—exclusive of the tops—contain *nearly ten times* as much of the two alkalies, potash and soda, as fifty bushels of wheat with its straw included.† What ground is there, then, for the explanation given by Liebig—of the peculiar qualities of the so-called wheat lands? We might with far greater show of reason assume the converse of his proposition, and infer that wheat does not prefer sandy soils, *because they are too rich in alkali!* It is singular, and would almost seem to strengthen this converse proposition, that beans, peas, and vetches, which are so often resorted to as a good preparative for wheat, contain also a much larger quantity of alkali than the latter grain. Thus the grain and straw together of twenty-six bushels of beans contain 71 lbs., of twenty bushels of peas 26 lbs., and of twenty bushels of vetches 74 lbs. of potash and soda taken together.

As I have already stated, however, we are not yet prepared for discussing this very curious and interesting question.

* On the thin chalk soils of the Yorkshire Wolds a crop of wheat is taken every four or five years, yielding an average of 24 or 25 bushels. The rotation is turnips, barley, clover or beans, wheat.

† According to the analyses of Sprengel given in the previous pages, ten tons of potatoes contain 143 lbs. of alkalies, twenty tons of turnips 154 lbs., and fifty bushels of wheat with its straw only 16 lbs.

§ 5. *Of the alleged constancy of the inorganic constituents of plants, in kind and quantity.*

In the preceding lecture (ix., p. 177), it was stated that the ash of the same plant, if ripe and healthy, is nearly the same in kind and quality in whatever circumstances (if favourable) of soil and climate it may grow. This *general* observation, however, is consistent with certain differences in the above respect, which are not without interest in their bearing upon agriculture both in theory and practice. Thus,

1°. The different parts of the same plant contain quantities of inorganic matter, not only different in their gross weights, but unlike also in the relative proportions of the several substances of which the entire ash consists. Both of these points have been previously illustrated (pp. 179, 180), and they are placed in the clearest light by the tabulated analyses introduced into the preceding section.

2°. The quantity and relative proportions of the different inorganic substances also vary with the season of the year at which the examination is made. Thus, according to De Saussure, plants of the same wheat which a month before flowering left 7·9 per cent. of ash, left when in flower only 5·4, and when ripe 3·3 per cent. The quantity of potash in the potato leaf diminishes very much as the plant approaches to maturity (Mollerat)—and the same has been observed in many saltworts and other sea-side plants. In the young plant of the *salsola clavifolia* there is much potash and no soda, but as its age increases the latter alkali appears, and gradually takes the place of the former.*

It is probably true, therefore, of all plants—that the ash both in kind and quantity is affected by the age at which the plant has arrived. It would appear that the unlike chemical changes which take place in the interior of the plant, at the successive periods of its growth, require the presence of different chemical agents—or that the production of new parts demands the co-operation of new substances.

3°. Similar differences are sometimes observed also when the same plant is grown in different soils. Thus it is known that the straw of the oat grown upon boggy land is very different in colour and lustre, from that yielded by the same variety of seed, when grown upon sound and solid soil. I lately examined two such portions of straw from the same seed—grown on the same farm on the estate of Dunglass, the one on boggy, the other on sound stiff land, when the straw from the

Sound land left 6·64 per cent. of ash, and from the
Boggy land " 6·2 per cent. of ash;

while the *silica* contained in the ash from the

Sound land amounted to 3·42 per cent., and from the
Boggy land " to 1·90 per cent. of the weight of the straw.

A remarkable difference, therefore, existed in the relative proportions,

* Meyen, *Jahresbericht*, 1839, p. 125. In regard to these salt-loving plants, which generally abound in soda, a curious observation was long ago made by Cadet. He states that if a plant of common salt-wort (*salsola sali*) be transplanted into an inland district—and seed from this plant be afterwards sown, the second race of plants will contain much potash, but scarcely a trace of soda.—Gmelin's *Handbuch der Chemie, II.* p. 1492. Potash may thus take the place of soda for a time, but removed from its native *habitat*, the plant would in a few generations die out and disappear.

at least of the silica, in these two varieties of straw, and this difference can be attributed only to the unlike nature of the soils in which the two samples were grown. But on boggy soils the oat plant is unhealthy, and in general neither fills its ear, nor ripens a perfect seed;—the difference in the ash in this case, therefore, cannot be considered as entirely opposed to the general proposition, that in a *healthy* state, plants at the same period of their growth always yield nearly the same weight of ash.

But that different experimenters have obtained very unlike quantities of ash, from the most common cultivated plants, apparently in a state of health, when grown under different circumstances of soil and climate, —does appear to contradict this general proposition. Thus 100 lbs. of *ripe wheat straw* leave of ash

4·3 lbs. De Saussure;
4·4 lbs. Berthier;
3·5 lbs. Sprengel;
15·5 lbs. Sir H. Davy;

while the straw of one variety of red wheat grown on a clay-loam, at Aykley Heads, near Durham, gave me 6·6 per cent., and that of two other varieties of red wheat, grown near Dalton, in Ravensworth Dale, Yorkshire, a country abounding in limestone—and on the same field—left respectively 12·15 and 16·5 per cent. of ash. The difference of 4 per cent. between these last two results, shows that the quantity of ash depends much upon the *variety* of grain examined—though to what extent all the great differences obtained, as above shown, are to be ascribed to this cause alone, it is impossible to say, until numerous other experiments shall have been instituted.

One thing, however, is manifest, that the quantities of inorganic matter necessarily contained in a crop of wheat, given in a previous page (p. 216) on the authority of Sprengel, must be considered as probably far below the mean proportion, since some varieties yield, in the form of ash, about six times as much as is there stated.

Every one knows how uncertain general conclusions are,—or explanations of natural phenomena,—when deduced from single observations only, and of this truth the above results present us with a useful illustration. Thus Liebig, in his *Organic Chemistry applied to Agriculture* p. 152, to which we have had frequent occasion to refer—explains why land will refuse to grow wheat, and may yet produce good crops of oats or barley in the following manner:—"One hundred parts of the stalks of wheat yield 15·5 parts of ashes (H. Davy): the same quantity of the dry stalks of barley 8·54 (Schrader), and one hundred parts of the stalks of oats only 4·42. The ashes of all are of the same composition. We have in these facts a clear proof of what plants require for their growth. Upon the same field which will yield only one harvest of wheat, two crops of barley and three of oats may be raised."

In this passage it has been assumed that the ash of wheat and other straws is constant in quantity, that wheat straw always contains much more than that of oats or barley, and that the *ash is in each case of the same composition* (see above, pp. 216 to 217),—all of which premises being incorrect, the conclusion must of course be rejected.

But the straw of barley and oats also, according to different authorities,

leaves very unlike quantities of ash. Thus, according to Sprengel and Schrader, 100 lbs. of

	Sprengel.	Schrader.	
Oat straw leave .	5·74 lbs.	4·42 lbs.	6·6 J.
Barley straw . .	5·24 lbs.	8·54 lbs.	

We cannot help conceding, therefore, generally, in regard to the cereal grasses, *that different* VARIETIES, at least, *of the same plant, may contain inorganic matter in different proportions.*

But certain analyses which have been made seem to demand a still further concession. Thus De Saussure found that the ash left by the same tree or shrub—by the fir or the juniper for example—differed both in kind and in quantity, according as it grew upon a granitic or calcareous soil. Berthier also found the ash of a piece of Norway pine (*pinus abies*) to differ very much from that of the wood of the same pine grown in France. From these and a few other observations, the conclusion has been very generally drawn by vegetable physiologists, that the ash of plants in general is determined both in kind and quantity *by the soil in which they grow.*

This is very likely to be true to a *certain extent*, as we have seen in the straw of the bog oat above adverted to, but a sufficient number of accurate comparative analyses of the ash of cultivated plants* has not yet been published, to enable us to determine the precise influence of the soil in all cases. It is impossible, however, that the prevailing character of the soil can have more than a *general influence* on the character of the ash of any living vegetable—*so long as the plant retains a healthy state.* The experiments of De Saussure do not appear to have been made with sufficient care,† while the only comparative experiment of Berthier is open to objections of another kind.

I have said that the quantity and kind of the ash is likely to be affected by the character of the soil to a *certain extent.* The following considerations seem to embody nearly all the sources of such variation, of which we can at present speak with any degree of certainty:—

1°. Plants at different periods of their growth require for the production of their several parts, and therefore appropriate from the soil, different inorganic substances;‡ hence the ash will vary with the age of the plant.

* Five samples of the same variety of wheat (Hunter's wheat) grown on different soils in the neighbourhood of Haddington, gave me very nearly the same proportions of ash. Thus the sample grown on a

	Per cent.
1°. Deep reddish clay loam, *subsoil* gravel, left	1·776
2°. Red clay on gravel	1·787
3°. Stiff clay on retentive subsoil	1·903
4°. Light clay on rather retentive subsoil . .	1·917
5°. Light turnip land	1·824

These results approach very near each other. The differences are perhaps too slight to justify us in concluding that the ash is greatest in quantity when the subsoil is most retentive.

† The accuracy of De Saussure's analyses is rendered very doubtful by the fact that, in the ash of *all* the different trees and shrubs he examined, he found a large quantity, in that of the juniper as much as 43 per cent. of *alumina*, and in that of the pine from 12 to 16 per cent., while Berthier, whose skill is undisputed, found no alumina in the ash of any of the numerous trees on which his experiments were made.

‡ This fact indicates an exceedingly interesting field of chemical research in connection with practical agriculture. What substance will bring this or that seed into early leaf?—what will hasten its growth in middle life?—what will bring it to early maturity? The wheat

2°. If the substances necessary for the perfection of one or more parts of a plant abound in the soil, its chief developement will take the direction of those parts. Thus one plant will run to leaf or straw, another to flower and seed. Thus also in the grain of one crop of wheat more gluten is produced than in that of another, and as this gluten appears to contain the phosphates of lime and magnesia, as essential constituents, the ash will necessarily vary with the gluten of the seed.

3°. Some substances appear to enter into the circulation of plants not so much as actual and necessary constituents of the parts of the vegetable, as to serve as media or agents by which other compounds, both organic and inorganic, may be conveyed to the plant. Thus common salt appears to enter many plants for the purpose of supplying soda, its chlorine being discharged by the leaf. Silica enters the plant chiefly in the form of silicate of potash or soda. When it reaches its proper destination—the stalks of the grasses for instance—this silicate is decomposed chiefly by the carbonic acid, which is always present in the pores of the green stem, the silica is deposited and the alkali proceeds downwards with the sap as a soluble carbonate, or in combination with some other organic acid. Thus the same portion of alkali may return many times into the circulation with this or with other materials which the parts of the plant require, and every new burden it deposits will necessarily cause a new variation in the relative proportions of the several inorganic constituents which are afterwards detected in the ash.

4°. As the water which enters by the roots always brings with it some soluble substances, the quantity of these conveyed into the plant will be materially affected by the amount of evaporation from the leaves; and hence, after a long drought, the leaves of the turnip, the potato, and other plants, will yield a larger proportion of ash than will be obtained from them in moist and rainy weather.

5°. In the mineral kingdom it is found that one substance may not unfrequently take the place, and perform the functions, of another. Thus potash and soda *replace* each other in certain minerals, as do also lime and magnesia and the phosphoric and arsenic acids. It has been supposed that a similar interchange may take place in the vegetable kingdom—that when the plant cannot get potash it will take soda—that when it can get neither, it will appropriate lime,—and so on. Such a conjectural interchange may possibly take place in a small degree, for a limited time, and in certain plants, without materially affecting their apparent health—but it is not by trusting to such resources of nature that a luxuriant vegetation or plentiful crops will ever be reared by the practical agriculturist.

Admitting, however, all these sources of variation in the kind and quantity of the ash obtained from different plants, the sound practical conclusions from all we know on the subject at present seem to be—

1°. That certain inorganic substances, in certain proportions, are necessary to all plants usually cultivated for food—if they are to be reared or maintained in a *healthy* state.

stalk and the potato require more potash while in rapid growth. This growth may be continued and prolonged by the presence of ammonia; while lime is said to bring it sooner to a close, and to give an earlier harvest. How valuable would be the multiplication of such facts!

2°. That we must seek for these *necessary* substances in the inorganic constituents which are present in the richest crops of every kind—in the produce of the most fertile soils.*

3°. That where these necessary substances are not present in any soil, we may infer that it will prove unfit to yield a luxuriant crop of a given kind; or, on the other hand, where these substances are not to be detected in the ash of the plant, that the fault of the crop, if any, may be ascribed to their partial or total absence from the soil on which it grew.

These conclusions form the basis of an enlightened and scientific practical agriculture. This basis, however, requires to be strengthened and enlarged by further experimental investigations.

* "I have examined," says Sprengel, "the finest seed-corns from many localities, and I have invariably found the quantities not only of the organic substances—starch, sugar, &c.—but also of the inorganic compounds in all the celebrated seed-corns, so perfectly alike, that one would have thought they had all grown on one and the same soil."—*Lehre vom Dünger*, p. 43.

LECTURE XI.

Nature and origin of soils.—Organic matter in the soil.—General constitution of the earthy part of the soil.—Classification of soils from their chemical constituents.—Method of approximate analysis for the purposes of classification.—General origin of soils and subsoils.—Structure of the earth's crust.—Stratified and unstratified rocks.—Crumbling or degradation of rocks.—Diversity of soils produced.—Superficial accumulations.—Tabular view of the character and agricultural capabilities of the soils of the different parts of Great Britain.

SUCH are the inorganic compounds which minister to the growth of plants, and such the proportions in which they severally occur in the living vegetable. Whence are these inorganic constituents all derived?

We have seen that the atmosphere, when pure, contains no inorganic matter, and that if dust, spray, or vapours occasionally float in the air, and are carried by the winds to great distances—yet that they are only accidentally present, and cannot be regarded as a source from which the general vegetation of the globe derives a constant supply of those mineral substances which are necessary to its healthy existence.

The soil on which they grow is the only natural source from which their inorganic food can be derived. We are led, therefore, as the next subject of our study, to inquire into the *nature* and *origin* of soils.*

§ 1. *Of the organic matter in the soil.*

Soils differ much as regards their immediate origin, their physical properties, their chemical constitution, and their agricultural capabilities; yet all soils which in their existing state are capable of bearing a profitable crop, possess one common character—they all contain *organic* matter in a greater or a less proportion.

This organic matter consists in part of decayed animal, but chiefly of decayed vegetable substances, sometimes in brown or black fibrous portions, exhibiting still, on a careful examination, something of the original structure of the organized substances from which they have been derived—sometimes forming only a fine brown powder intimately intermixed with the mineral matters of the soil—sometimes scarcely perceptible in either of those forms, and existing only in the state of organic compounds more or less void of colour and at times entirely soluble in water. In soils which appear to consist only of pure sand, or clay, or chalk, organic matter in this latter form may often be detected in considerable quantity.

The proportion of organic matter in soils which are naturally productive of any useful crops, varies from one-half to 70 per cent. of their whole weight. With less than the former proportion they will scarcely support vegetation—with more than the latter, they require much admixture before they can be brought into profitable cultivation. It is

* On the subject of this and the following lecture, the reader will consult with advantage an excellent little work, "*On the nature and property of soils*," by Mr. John Morton.

only in boggy and peaty soils that the latter large proportion is ever found—in the best soils the organic matter does not average five per cent., and rarely exceeds ten or twelve. Oats and rye will grow upon land containing only one or one and a half per cent.—barley where two or three per cent. are present—but good wheat soils contain in general from 4 to 8 per cent., and, if very stiff and clayey, from 10 to 12 per cent. may occasionally be detected.

Though, however, a certain proportion of organic matter is always found in a soil distinguished for its fertility, yet the presence of such substances is not alone sufficient to impart fertility to the land. I do not allude merely to such as, like peaty soils, contain a very large excess of vegetable matter, but to such also as contain only an average proportion. Thus of two soils in the same neighbourhood—the one contained 4·05 per cent. of organic matter, and was very fruitful—the other 4·19 per cent., and was almost barren. This fact is consistent with what has been stated in the two preceding lectures, in regard to the influence exercised by the dead *inorganic* matter of the soil, on the general health and luxuriance of vegetation.

§ 2. *General constitution of the earthy part of the soil.*

From what is above stated, it appears that, on a general average, the earthy part of the soil in our climate does not constitute less than 96 per cent. of its whole weight, when free from water. This earthy part consists principally of three ingredients:—

1°. Of *Silica*, siliceous sand, or siliceous gravel—of various degrees of fineness, from that of an impalpable powder as it occurs in clay soils, to the large and more or less rounded sandstones of the gravel beds.

2°. *Alumina*—generally in the form of clay, but occasionally occurring in shaly or slaty masses more or less hard, intermingled with the soil.

3°. *Lime*, or carbonate of lime—in the form of chalk, or of fragments more or less large of the various limestones that are met with near the surface in different countries. Where cultivation prevails it often happens that all the lime which the soil contains has been added to it for agricultural purposes—in the form of quick-lime, of chalk, of shell-sand, or of one or other of the numerous varieties of marl which different districts are known to produce.

It is rare that a superficial covering is anywhere met with on the surface of the earth, which consists solely of any one of these three substances—a soil, however, is called *sandy* in which the siliceous sand greatly predominates, and *calcareous*, where, as in some of our chalk and limestone districts, carbonate of lime is present in considerable abundance. When alumina forms a large proportion of the soil, it constitutes a *clay* of greater or less tenacity.

The term *clay*, however, or *pure clay*, is never used by writers on agriculture to denote a soil consisting of alumina only, for none such ever occurs in nature. The pure *porcelain clays* are the richest in alumina, but even when free from water they contain only from 42 to 48 per cent. of this earth, with from 52 to 58 of silica. These occur, however, only in isolated patches, and never alone form the soil of any considerable

district. The strongest clay soils which are anywhere in cultivation rarely contain more than 35 per cent. of alumina.*

Soils in general consist in great part of the three substances above named in a state of *mechanical mixture*. This is always the case with the siliceous sand and with the carbonate of lime—but in the clays the silica and the alumina are, for the most part, in a state of *chemical combination*. Thus, if a portion of a stiff clay soil be kneaded or boiled with repeated portions of water till its coherence is entirely destroyed, and if the water, with the finer parts which float in it, be then poured into a second vessel, the whole of the soil will be separated into two portions—a fine impalpable powder consisting chiefly of clay, poured off with the water, and a quantity of siliceous or other sand in particles of various sizes, which will remain in the first vessel. This sand was only mechanically mixed with the soil. The fine clay retains still some mechanical admixtures, but consists chiefly of silica and alumina chemically combined.

Of the porcelain clays above alluded to, there are several varieties, three of which, containing the largest proportion of alumina, consist respectively of—

	I.	II.	III.
Silica . .	47·03	46·92	46·0
Alumina .	39·23	34.81	40·2
Water . .	13·74	18·27	13·8
	100·00	100·00	100·0†

But, as already stated, these clays rarely form a soil—the stiffest clays treated by the agriculturist containing a further portion of silica, some of which is mechanically mixed, and can be partially separated by mechanical means.

The strongest agricultural clays (*pipe-clays*) of which trustworthy analyses have yet been published, consist, in the dry state, of 56 to 62 of silica, from 36 to 40 of alumina, 3 or 4 of oxide of iron, and a trace of lime. Clays of this composition are distinguished by the foreign agricultural writers as *pure clays*. They are all probably made up of some of the varieties of porcelain clay, more or less intimately mixed with siliceous and ochrey particles—in so minute a state of division that they cannot be separated by the method of decantation above described.

These *clays* are adopted by the German and French writers as a standard to which they can liken clay soils in general, and by comparison with which they are enabled distinctly to classify and name them. As the use of the term *clay* in this sense has been introduced into Eng-

* In an interesting paper on subsoil ploughing by Mr. H. S. Thompson, in the report of the Yorkshire Agricultural Society for 1837, p. 47, it is stated that the lias clays, which form the subsoil in certain parts of Yorkshire, contain sometimes, *in the dry state, as much as 54 per cent. of alumina* (!)

† When heated to redness the whole of the water is driven off from these clays, and they then consist respectively of—

Silica	54·5	57·4	53·4
Alumina	45·5	42·6	46·6
.....	100·0	100·0	100·0

which numbers are in accordance with those given at the foot of the preceding page.

lish agricultural books,* and as it is really desirable to possess a word to which the above meaning can be attached, I shall venture in future to employ it always strictly in this *agricultural sense.*

By alumina, then, I shall in all cases express the pure earth of alum, which exists in clays, and to which they owe their tenacity—by CLAY, *a finely divided chemical compound, consisting very nearly of* 60 *of silica and* 40 *of alumina, with a little oxide of iron, and from which no siliceous or sandy matter can be separated mechanically or by decantation.*

Of this clay the earthy part of all known soils is made up by mere mechanical admixture with the other earthy constituents (sand and lime), in variable proportions. On a knowledge of these proportions the following general classification and nomenclature are founded.

§ 3. *Of the classification of soils from their chemical constituents.*

Upon the principles above described soils may be classified as follows:—

1°. *Pure clay* (pipe-clay) consisting of *about* 60 of silica and 40 of alumina and oxide of iron, for the *most part* chemically combined. It allows no siliceous sand to subside when diffused through water, and rarely forms any extent of soil.

2°. *Strongest clay soil* (tile-clay, unctuous clay) consists of pure clay mixed with 5 to 15 per cent. of a siliceous sand, which can be separated from it by boiling and decantation.

3°. *Clay loam* differs from a clay soil, in allowing from 15 to 30 per cent. of fine sand to be separated from it by washing, as above described. By this admixture of sand, its parts are mechanically separated, and hence its freer and more friable nature.

4°. A *loamy soil* deposits from 30 to 60 per cent. of sand by mechanical washing.

5°. A *sandy loam* leaves from 60 to 90 per cent. of sand, and

6°. A *sandy soil* contains no more than 10 per cent. of pure clay.

The mode of examining with the view of naming soils, as above, is very simple. It is only necessary to spread a weighed quantity of the soil in a thin layer upon writing paper, and to dry it for an hour or two in an oven or upon a hot plate, the heat of which is not sufficient to discolour the paper—the loss of weight gives the water it contained. While this is drying, a second weighed portion may be boiled or otherwise thoroughly incorporated with water, and the whole then poured into a vessel, in which the heavy sandy parts are allowed to subside until the fine clay is beginning to settle also. This point must be carefully watched, the liquid then poured off, the sand collected, dried as before upon paper, and again weighed. This weight is the quantity of sand in the known weight of *moist* soil, which by the previous experiment has been found to contain a certain quantity of water.

Thus, suppose two portions, each 200 grs., are weighed, and the one in the oven loses 50 grs. of water, and the other leaves 60 grs. of sand, —then, the 200 grs. of *moist* are equal to 150 of *dry*, and this 150 of dry

* As in *British Husbandry*, p. 113, and in *Loudon's Encyclopædia of Agriculture*, p. 315, where classifications of soils are given chiefly from Von Thaer, though neither work exhibits with sufficient prominence the meaning to be attached to *agricultural clay*, as distinguished from alumina, sometimes called *pure clay* by the chemist.

soil contain 60 of sand, or 40 in 100 (40 per cent.) It would, therefore, be properly called a *loam*, or *loamy soil*.

But the above classification has reference only to the clay and sand, while we know that lime is an important constituent of soils, of which they are seldom entirely destitute. We have, therefore,

7°. *Marly soils*, in which the proportion of lime is more than 5 but does not exceed 20 per cent. of the whole weight of the dry soil. The marl is a sandy, loamy, or clay marl, according as the proportion of clay it contains would place it under the one or other denomination, supposing it to be entirely free from lime, or not to contain more than 5 per cent., and

8°. *Calcareous soils*, in which the lime exceeding 20 per cent. becomes the distinguishing constituent. These are also calcareous clays, calcareous loams, or calcareous sands, according to the proportion of clay and sand which are present in them.

The determination of the lime also, when it exceeds 5 per cent., is attended with no difficulty.

To 100 grs. of the dry soil diffused through half a pint of cold water, and half a wine-glass full of muriatic acid (the spirit of salt of the shops), stir it occasionally during the day, and let it stand over-night to settle. Pour off the clear liquor in the morning and fill up the vessel with water, to wash away the excess of acid. When the water is again clear, pour it off, dry the soil and weigh it—the loss will amount generally to about one per cent. more than the quantity of lime present. The result will be sufficiently near, however, for the purposes of classification. If the loss exceed 5 grs. from 100 of the dry soil, it may be classed among the marls, if more than 20 grs. among the calcareous soils.

Lastly, vegetable matter is sometimes the characteristic of a soil, which gives rise to a further division of

9°. *Vegetable moulds*, which are of various kinds, from the garden mould, which contains from 5 to 10 per cent., to the peaty soil, in which the organic matter may amount to 60 or 70. These soils also are clayey, loamy, or sandy, according to the predominant character of the earthy admixtures.

The method of determining the amount of vegetable matter for the purposes of classification, is to dry the soil well in an oven, and weigh it; then to heat it to dull redness over a lamp or a bright fire till the combustible matter is burned away. The loss on again weighing is the quantity of organic matter.

Summary.—The several steps, therefore, to be taken in examining a soil with the view of so far determining its constitution as to be able precisely to name and classify it, will be best taken in the following order:—

1°. Weigh 100 grains of the soil, spread them in a thin layer upon white paper, and place them for some hours in an oven or other hot place, the heat of which may be raised till it only does not discolour the paper. The loss is water.

2°. Let it now (after drying and weighing) be burned over the fire as above described. The second loss is organic, chiefly vegetable matter, with a little water, which still remained in the soil after drying.

3°. After being thus burned, let it be put into half a pint of water

with half a wine-glass full of spirit of salt, and frequently stirred. When minute bubbles of air cease to rise from the soil on settling, this process may be considered as at an end. The loss by this treatment will be a little more than the true per centage of lime,* and it will generally be nearer the truth if that portion of soil be employed which has been previously heated to redness.

4°. A fresh portion of the soil, perhaps 200 grs. in its moist state, may now be taken and washed to determine the quantity of siliceous sand it contains. If the residual sand be supposed to contain calcareous matter its amount may readily be determined by treating the dried sand with diluted muriatic acid, in the same way as when determining the whole amount of lime (3°.) contained in the unwashed soil.†

Let me illustrate this by an example.

Example.—Along the outcrop of some of the upper beds of the green sand in Berkshire, Wiltshire, and Hampshire, and probably also in Buckingham and Bedford, occur patches of a loose friable *grey* soil mixed with occasional fragments of flint, which is noted for producing excellent crops of wheat every other year. It is known in the valley of Kingsclere, at Wantage, and Newbury. I select a portion of this soil from the latter locality for my present illustration.

1°. After being dried in the air, and by keeping some time in paper, it was exposed for some hours to a temperature sufficient to give the white paper below it a scarcely perceptible tinge: by this process 104½ grs. lost 4 grs.

2°. When thus dried, it was heated to dull redness. It first blackened, and then gradually assumed a pale brick colour, the change, of course, beginning at the edges. The loss by this process was 4½ grs.

3°. After this heating, it was put into half a pint of pure rain water with half a wine-glass full of spirit of salt. After some hours, when the action had ceased, the soil was washed and dried again at a dull red heat. The loss amounted to 3 grs.

The soil, therefore, contained

Water	4 grs.
Organic matter (less than) . .	4½
Carbonate of lime (less than) .	3
Clay and sand	93½
	104½

4°. By boiling and washing with water, 291 grs. of the undried soil left 202½ grs. of very fine sand chiefly siliceous,—104½, therefore, would have left 73 grs., or the soil contained per cent.—

* A more rigorous method of determining the lime when less than 5 per cent. will be given in the following lecture.

† The weighings for the purposes here described may be made in a small balance with grain weights, sold by the druggists for 5s. or 6s., and the vegetable matter may be burned away on a slip of sheet iron or in an untinned iron table-spoon over a bright cinder or charcoal fire—care being taken that no scale of oxide, which may be formed on the iron, be allowed to mix with the soil when cold, and thus to increase its weight. Those who are inclined to perform the latter operation more neatly, may obtain for about 6s. each—from the dealers in chemical apparatus—thin light platinum capsules from 1 to 1½ inches in diameter, capable of holding 100 grs. of soil—and for a few shillings more a spirit lamp, over which the vegetable matter of the soil may be burned away. With care, one of these little capsules will serve a life-time.

Water	3·9 per cent.
Organic matter (less than) . .	4·1
Carbonate of lime (less than) .	3·0
Clay	19·0
Sand (very fine)	70·0
	100·0*

This soil, therefore, containing 70 per cent. of sand, separable by decantation, is properly a *sandy loam.*

§ 4. *Of the distinguishing characters of soils and subsoils.*

Beneath the immediate surface soil, through which the plough makes its way, and to which the seed is entrusted, lies what is commonly distinguished by the name of *subsoil.* This subsoil occasionally consists of a mixture of the general constituents of soils naturally different from that which forms the surface layer—as when clay above has a sandy bed below, or a light soil on the surface rests on a retentive clay beneath.

This, however, is not always the case. The peculiar characters of the soil and subsoil often result from the slow operation of natural causes.

In a mass of loose matter of considerable depth, spread over an extent of country, it is easy to understand how—even though originally alike through its whole mass—a few inches at the surface should gradually acquire different physical and chemical characters from the rest, and how there should thus be gradually established important agricultural distinctions between the first 12 or 15 inches (the soil), the next 15 (the subsoil), and the remaining body of the mass, which, lying still lower, does not come under the observation of the practical agriculturist.

On the surface, plants grow and die. Through the first few inches their roots penetrate, and in the same the dead plants are buried. This portion, therefore, by degrees, assumes a brown colour, more or less dark, according to the quantity of vegetable matter which has been permitted to accumulate in it. Into the subsoil, however, the roots rarely penetrate, and the dead plants are still more rarely buried at so great a depth. Still this inferior layer is not wholly destitute of vegetable or other organic matter. However comparatively impervious it may be, still water makes its way through it, more or less, and carries down *soluble organic substances,* which are continually in the act of being produced during the decay of the vegetable matter lying above. Thus, though not sensibly discoloured by an admixture of decayed roots and stems, the subsoil in reality contains an appreciable quantity of organic matter which may be distinctly estimated.

Again, the continual descent of the rains upon the surface soil washes down the carbonates of lime, iron, and magnesia, as well as other soluble earthy substances—it even, by degrees, carries down the fine clay also,

* Some of these numbers differ by a minute fraction from those in the preceding page: this is because they are calculated from the more correct decimal fractions contained in my own note-book. The organic matter is said to be *less than* the number here given, because by simple drying, as here prescribed, the whole of the water cannot be driven off—a portion being always retained by the clay, which is not entirely expelled, till the soil is raised nearly to a red heat. Hence the loss by this second heating must always be greater than the actual weight of organic matter present. The lime is also *less than* the number given, because, as already stated, the acid dissolves a little alumina as well as any carbonate of magnesia which may be present.

so as gradually to establish a more or less manifest difference between the upper and lower layers, in reference even to the earthy ingredients which they respectively contain.

But, except in the case of very porous rocks or accumulations of earthy matter, these surface waters rarely descend to any great depth, and hence after sinking through a varjable thickness of subsoil, we come, in general, to earthy layers, in which little vegetable matter can be detected, and to which the lime, iron, and magnesia of the superficial covering has never been able to descend.

Thus the character of the *soil* is, that it contains more brown organic, chiefly vegetable, matter, in a state of decay—of the *subsoil*, that the organic matter is less in quantity and has entered it chiefly in a soluble state, and that earthy matters are present in it which have been washed out of the superior soil—and of the *subjacent mass*, that it has remained nearly unaffected by the changes which vegetation, culture, and atmospheric agents have produced upon the portions that lie above it.

From what is here stated, the effect of trench and subsoil ploughing, in altering more or less materially the proportions of the earthy constituents in the surface soil, will be in some measure apparent. That which the long action of rains and frosts has caused to sink beyond the ordinary reach of the plough is, by such methods, brought again to the surface. When the substances thus brought up are directly beneficial to vegetation or are fitted to improve the texture of the soil, its fertility is increased. Where the contrary is the case, its productive capabilities may for a longer or a shorter period be manifestly diminished.

§ 5. *On the general origin of soils.*

On many parts of the earth's surface the naked rocks appear over considerable tracts of country, without any covering of loose materials from which a soil can be formed. This is especially the case in mountainous and granitic districts, and in the neighbourhood of active or extinct volcanoes, where, as in Sicily, streams of naked lava stretch in long black lines amid the surrounding verdure.

But over the greater portion of our islands and continents the rocks are covered by accumulations, more or less deep, of loose materials—sands, gravels, and clays chiefly—the upper layer of which is more or less susceptible of cultivation, and is found to reward the exertions of human industry with crops of corn in greater or less abundance.

This superficial covering of loose materials varies from a few inches to one or two hundred feet in depth, and is occasionally observed to consist of different layers or beds, placed one over the other—such as a bed of clay over one of gravel or sand, and a loamy bed under or over both. In such cases the characters and capabilities of the soil must depend upon which of these layers may chance to be uppermost—and its character may often be beneficially altered by a judicious admixture with portions of the subjacent layers.

It is often observed, where naked rocks present themselves, either in cliffs or on more level parts of the earth, that the action of the rains and frosts causes their surfaces gradually to shiver off, crumble down, or wear away. Hence at the base of cliffs loose matter collects—on comparatively level surfaces the crumbling of the rock gradually forms a soil—

while from those which are sufficiently inclined the rains wash away the loose materials as soon as they are separated, and carry them down to the vallies.

The superficial accumulations of which we have spoken, as covering the rocks in many places to a depth of one or two hundred feet, consist of materials thus washed down or otherwise transported—by water, by winds, or by other geological agents. Much of these heaps of transported matter is in the state of too fine a powder to permit us to say from whence it has been derived—but fragments of greater or less size are always to be found, even among the clays and fine sands, which are sufficient to point out to the skilful geologist the direction from which the whole has been brought, and often the very rocks from which the entire accumulations have been derived.

Thus the general conclusion is fairly drawn, that the earthy matter of *all* soils has been produced by the gradual decay, degradation, or crumbling down of previously existing rocks. It is evident therefore—

1°. That whenever a soil rests immediately upon the rock from which it has been derived, it may be expected to partake more or less of the composition and characters of that rock.

2°. That where the soil forms only the surface layer of a considerable depth of transported materials, it may have no relation whatever either in mineralogical characters or in chemical constitution to the immediately subjacent rocks.

The soils of Great Britain are divisible into two such classes. In some counties an acquaintance with the prevailing rock of the district enables us to predict the general characters and quality of the soil; in others—and nearly all our coal fields are in this case—the general character and capabilities of the soil have no relation whatever to the rocks on which the loose materials rest.

§ 6. *On the general structure of the earth's crust.*

Beneath the soil, and the loose or drifted matters on which it rests, we everywhere find the solid rock. This rock in most countries is seen—in mines, quarries, and cliffs—to consist of beds or layers of varied thickness placed one over the other. To these layers geologists give the name of *strata*; and hence rocks which are thus made up of many separate layers are called *stratified* rocks.

But in some places entire mountain masses are met with, in which no parting into layers or beds is seen, but which appear to consist of one unbroken rock of the same material from their upper surface downwards, and often as far beneath as we have been able to penetrate into the earth. Such rocks are said to be *unstratified*. Among these are included the granites, the trap, green-stone, or basaltic rocks, and the lavas. Geologists have ascertained that all these unstratified rocks have, like the volcanic lavas, been in a more or less perfectly melted state—that their present appearance is owing to the action of fire—and hence they are often called *igneous** rocks. They often also exhibit a more or less crystalline or glassy structure, or contain, imbedded in them, numerous regular crystals of mineral substances; hence they are sometimes called also *crystalline* rocks. The terms igneous, crystalline, and

* Sometimes *pyrogenous*, produced by fire; but this is an unnecessarily *hard* word.

unstratified, therefore, apply to the same class of rocks—the first indicating their *origin*, the second their structure *in the small*, the third their structure *in the large*, as distinguished from that of the rocks which occur in beds.

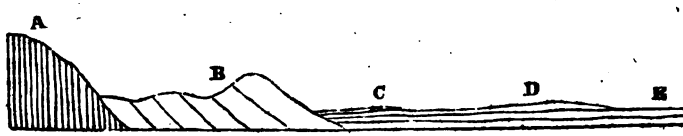
The following diagram exhibits the general appearance of the stratified rocks as they are found to occur in contact with unstratified masses in various parts of the globe :—

A represents an unstratified mountain mass or other similar rock rising up through the stratified deposits. The bending up of the edges of the latter indicates that after the beds were deposited in a nearly level position, the mass A was intruded or forced up through them, carrying the broken edges of the beds along with it.

B shows the more quiet way in which veins or dykes of unstratified green-stone, or trap, or lava, cut through the beds without materially displacing them—as if when in a fluid state it had risen up and filled a previously existing crack or chasm. In Devonshire, in the North of Scotland, and in Ireland, the granite rises in many places exactly as is shown at A, and nearly all our coal fields exhibit in their whin dykes numerous illustrations of what is shown at B.

C and D exhibit the manner in which the strata overlie one another in nearly a horizontal position—1, 2, 3, indicating different kinds of rock, —as a lime-stone, a sand-stone, and a clay—which again are subdivided into beds or thinner layers, by the partings exhibited in the wood-cut.

The stratified rocks lie sometimes nearly level or horizontal over large tracts of country—as in the above diagram,—sometimes they are more or less inclined or appear to dip in one and to rise in the opposite direction—as if a surface, formerly level, had been pushed down at the one end and raised up at the other,—and sometimes they seem to rest entirely upon their edges. Upon the mode in which they thus lie, the *uniformity* of the soil, in a district where it reposes immediately on the rocks from which it is derived, is materially dependent. In the following diagram the surface from A to E represents a tract of country in which the



rocks have in different parts these different degrees of inclination, at A vertical, at B more inclined, and from C to E nearly horizontal. Now, it is obvious that if the outer surface of these several rocks crumble and form a soil which rests where it is produced—then the quality of the soil on every spot will be determined by the nature of the rock beneath. Hence, in proceeding from E over the comparatively level strata, we shall find the soil pretty uniform in quality till we come to the edge of

the bed D, thence it will again be uniform, though perhaps different from the former, till we reach the stratum C, when again it will prove uniform over a considerable space till we begin to climb the hill to B. So the whole hill-side in ascending to B will be of one and the same kind of soil. But as we descend on the other side and pass B, we get upon the edges of the beds, and then as we proceed from one bed to another, the quality of the soil may vary every few yards, more or less, according as the members of this group of beds are more or less different from each other. But when we ascend the hill to A, where the beds, besides being vertical, are also very thin, the soil may change at almost every step, provided—which is, however, rarely the case among the rocks (slate rocks) which occur most frequently in this position—provided the mineralogical characters of the several vertical layers be sensibly unlike. Such dissimilarities in the angular position of the strata, as are represented in the above diagram, are of constant occurrence, not only in our islands, but in all parts of the globe; and they illustrate very clearly *one* important natural cause of that want of uniformity in the nature and capabilities of the soil which is more or less observable in every undulating and in some comparatively level countries also.

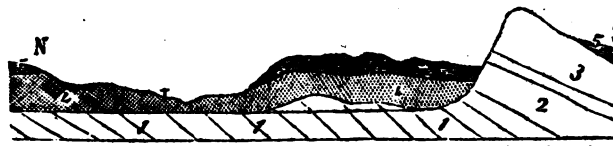
It may be stated, as the general result of an extended examination of all the stratified rocks yet known—that they consist of alternations or admixtures of three kinds of rock only—of sand-stones, of lime-stones, and of clays. The sand-stones are of various degrees of solidity and hardness, from the loose sand of some parts of the lower new-red and green-sand formations, to the almost perfect quartz rock not unfrequently associated with the oldest strata. The lime-stones vary in like manner from the soft chalk to the hard mountain lime-stone and the crystalline statuary marble; while the clays are found of all degrees of hardness from that of the London and Kimmeridge clays, which soften in water, to that of the roofing slates of Cumberland and Wales,—and even to that of the gneiss rocks which rest immediately upon the granite, and which appear to be only the oldest clays altered by the action of heat.

But the stratified rocks, though thus distinguishable into three main varieties—rarely consist of any one of these substances in an unmixed state. The sand-stones not unfrequently contain a little clay or lime, while the lime-stones and clays are often mixed with sand and with each other.

If the stratified rocks thus consist essentially of these three substances, the soils formed from them by natural crumbling or decay must have a similar composition. A sandy soil will be formed from a sand-stone,—a calcareous soil from a lime-stone,—a clay from a slate or shale,—and from a mixed rock, a soil containing a mixture of two or more of these earthy ingredients—in proportions which will depend upon the relative quantities of each which are contained in the rock from which they have been derived.

§ 7. *Relative positions and peculiar characters of the several strata.*

1°. The several strata, or series of strata, which present themselves in the crust of the globe, always maintain the same relative positions. Thus the numbers 3, 2, 1, in the annexed diagram, represent three series of beds known by the names of the magnesian lime-stone, the lower new-



red sand-stone, and the coal-measures, lying over each other in their natural positions—the lime-stone uppermost, the sand-stone next, and the coal beneath both. Whenever these three rocks are met with, near each other, they always occupy the same relative position, the coal never appears above this lime-stone, and the sand-stone, if present, is always between the two other series of beds. The same is true of every other group of strata—the order in which they are placed over each other is universally the same.

2°. These beds are generally continuous also over very large areas—or are found to stretch, without interruption, over a great extent of country. Hence when they dip beneath other beds, as they are seen to do in the above diagrams, we can still, with a high degree of probability, infer their presence at a greater or less depth, wherever we observe on the surface those other beds which are known usually to lie immediately above them. Thus, if in a tract of country consisting of the magnesian lime-stone (3) above-mentioned, it is known that deep vallies occur, it becomes probable that the soil in those vallies will rest upon, and may be formed from, the underlying red sand-stones or coal-measures; and that it will therefore possess very different agricultural capabilities from the soil that generally prevails around it. Or in chalk districts, beneath which usually lies the green-sand, the presence of a deep valley cutting through the chalk almost necessarily implies in the hollow a very different soil from that which is cultivated in the chalk wolds above. This is the case in the valley of Kingsclere, where the peculiar wheat soil occurs, of which an approximate analysis has been given in page 234.

3°. It has been already stated that the stratified rocks, though so very numerous and so varied in appearance, yet consist generally of repeated alternations of lime-stones, sand-stones, and clays, or of mixtures of two or more of these earthy substances. But the several series of strata are nevertheless distinguished from each other by peculiar and often well-marked characters.

Thus some are soft, crumble readily, and soon form a soil,—while others, though consisting of the same ingredients, long refuse to break into minute fragments, and thus condemn the surface of the country where they occur to more or less partial barrenness.

In others, again, the proportions of sand or lime are so varied, from bed to bed, that the character of the mixture in each is entirely different—so that while one, on crumbling down, will give a stiff clay, another will produce a loam, and a third a sandy marl.

Or, in some rocks the remains of vegetables are present in considerable quantity,—as in the neighbourhood of our coal-beds—or the bones or shells of animals in greater or less abundance, by each of which the agricultural characters and capabilities of the soils formed from them, will be more or less extensively affected.

Or lastly, the mixture of other earthy substances gives a peculiar

character to many rocks. Thus the per-oxide of iron, which imparts their red colour to many strata—as to the red sandstones—influences not only the mineralogical character of the rock, but also the quality of the soil which is formed by its decay. In like manner the presence of magnesia, sometimes in large quantity, in many lime-stones, produces an important modification in the chemical constitution and mineralogical characters of the rock, as well as in its relations to practical agriculture.

In consequence of these and other similar causes of diversity, if not every stratum, at least every series of strata, exhibits distinguishing and characteristic peculiarities, by means of which it may be more or less readily recognized. On these peculiarities the special agricultural capabilities of those parts of the globe in which each series of beds occurs are in a great degree dependent.

4°. This peculiar character is also more or less continuous over very large areas. Thus if a given stratum be found on the surface in any part of England, and again in any part of Russia, the soil formed from that bed will generally exhibit very nearly the same qualities in both countries. A knowledge of the geology, therefore,—that is, of the kind of rock which appears on the surface in every part of a country—enables us to predict generally the kind of soil which ought to rest upon it, if it be not covered by foreign accumulations; while, on the other hand, a knowledge of the agricultural capabilities of any one district in which certain rocks are known to lie immediately beneath the soil, and of the agricultural practice suited to that district, will indicate the probable capabilities of any other tract in which the same kind of rock is known to appear on the surface, and of the kind of culture which may be most successfully applied to it.

It is evident, then, that a familiar acquaintance with the general characters and relative positions of all the series of strata that have hitherto been observed, and of the classification of rocks considered geologically, to which this knowledge has led, must be fitted to throw much light upon the principles of a general, enlightened, and philosophical agriculture.

§ 8. *Classification of the stratified rocks, their extent, and the agricultural relations of the soils derived from them.*

It is a received principle, I may say rather, an obvious fact, that in the crust of the earth, as in the walls of a building, those layers which lie lowest or undermost have been first deposited, or are the *oldest*. In reference to this their relative age, the stratified rocks are divided into the primary, the first deposited and most ancient—the secondary, which are next in order—and the tertiary, which overlie both.

These three series of strata are again subdivided into *systems*, and these into minor groups, called *formations*,—the several members of each system and formation having such a common resemblance, either in mineralogical character or in the kind of animal and vegetable remains found in them, as to show that they were deposited under very nearly the same general physical conditions of the globe.

The following table exhibits the names, relative positions, thicknesses, and mineralogical characters of the stratified rocks, in descending order, *as they occur in our islands*. The annexed remarks indicate also the

districts where each of these groups of rocks forms the surface, and the general agricultural character of the soils that rest upon them.

I. TERTIARY STRATA—characterized by containing, among other fossils, the remains of animals, which are identical with existing species.

NAME AND THICKNESS.	MINERALOGICAL CHARACTERS.
1°. *Crag.* 50 *ft.*	A mass of rolled pebbles mixed with marine shells—resting on beds of sand and sandy lime-stone; the whole more or less impregnated with oxide of iron.

EXTENT.—The Crag forms a stripe of land a few miles in width in the eastern part of Norfolk and Suffolk, and in the south-eastern part of the latter county. It is a flat, and generally, it is said, a fertile arable district.

2°. *Fresh-water Marls.* 100 *ft.*	Marls and marly lime-stones, with fresh-water shells divided into two series by an estuary deposit, containing marine shells.

EXTENT.—On these beds reposes the soil of the northern half of the Isle of Wight, the only part of England in which they appear at the surface.

3°. *London Clay.* 200 *to* 500 *ft.*	Stiff, almost impervious, brown, blue, and blackish clay, rich in marine shells, and containing layers of lime-stone nodules.

EXTENT.—The greater part of the county of Middlesex, the south-eastern half of Essex, and the southern half of Hampshire, rest upon the London Clay.

SOIL.—The soil is naturally strong, heavy, wet, and tenacious, "sticking to the plough like pitch," and shrinking and cracking in dry weather. Where it is mixed with sand, it forms a fertile loam; and hence where the sand of the subjacent plastic clay is easily accessible, it may readily be improved by admixture. Repeated dressings of London manure convert it into rich meadow land, and even where this cannot be obtained, the difficulty and expense of culture have caused a very large portion of it to be retained in pasture. That which is under culture is said to be too strong for turnips and barley, but to grow excellent crops of wheat and beans.

4°. *Plastic Clay.* 300 *to* 400 *ft.*	Alternating beds of clay and sand, of various colours and thicknesses. Some of the beds of clay are pure white, and so fine as to be used for making pipes.

EXTENT.—This formation surrounds the London clay with an indented, generally low, and flat belt, of varying breadth, occupying a large space in Hampshire and Dorset, in Essex, Suffolk, and Norfolk,—stretching along the northern part of Kent and Surrey, and throwing out arms into Berks, Buckingham, and Hertford.

SOIL.—The soil is very various, the alternate beds of sand and clay of different qualities producing soils of the most unlike quality often within very short distances. The greatest portion of this tract is in arable culture, but there are extensive heaths and wastes in Berks, Hampshire, and Dorset.

In Norfolk and Suffolk, where the lower beds of this sand rest upon chalk, the soil is readily changed, by an admixture with this chalk, into a good sandy loam, which will yield large crops of turnips, barley, and wheat, instead of the heath and bent, its sole original produce. This chalking is generally repeated once in 8 years, at an expense of 50s. an acre. In Hampshire and Berkshire, the same method is adopted with great success, and the rich crops now reaped from Hounslow Heath are the result of this method of improvement.

II. The SECONDARY STRATA—contain *no* animal remains which can be identified with existing species. Those which are found in them are nearly *all* different from those which occur either in the tertiary above or the primary strata below.

A.—CRETACEOUS SYSTEM.

5°. *Chalk.*	600 *ft.*	The upper part softer, and containing layers of flints, with many marine remains. Below, the chalk is harder, and towards the bottom passes into beds of marl—(chalk marl).

EXTENT.—The chalk occupies a very large area in the south-eastern part of the island. It forms a broad band of from 15 to 25 miles in breadth, running north-east and south-west from the extreme south-western part of Dorset, to the extreme north of Norfolk,—it there turns nearly at a right angle, into the centre of Lincolnshire, where it is 10 to 15 miles in breadth, and thence stretches into Yorkshire, in the south-eastern part of which county it covers a large area, and about Flamborough Head attains a breadth of 25 miles. In passing through Berkshire and Surrey, it is partially interrupted by the plastic clay which it embraces on every side; and hence, in following the outline of this formation it encircles with a broad fringe the southern edges of Sussex and Surrey and the northern borders of Kent.

SOIL.—The soils formed from the upper chalk are all more or less mixed with flints, and they produce naturally a very short but excellent sheep pasture. A great portion of this chalk-land in Dorset, Wilts, and Berks, has been occupied as a sheep-walk for ages, though under proper cultivation it is said to be convertible into good arable land, producing barley, turnips, wheat, and sainfoin. The lower chalk soils (chalk marl) consist of a deep, strong, calcareous grey or white loam, *very productive*, and when mixed with the green sand below it, becoming still richer, more friable, and more productive of every kind of crop. It is better suited for wheat than the upper chalk, but is less adapted for turnips.

The porous nature of the chalk renders the soil very dry, and in many localities the only method of obtaining a sufficient supply of water is by forming ponds to catch and retain the rain-water.

In Norfolk and Suffolk, on the Lincolnshire, and more recently on the Yorkshire Wolds, great improvement has been effected by dressing the chalk-soil with fresh chalk brought up from a considerable depth below, and laid on at the rate of 50 to 80 cubic yards per acre. The explanation of this procedure is to be found in the fact above stated, that the lower chalk marls, without flints, produce an excellent soil, fitted therefore, by admixture with the poorer upper-chalk soils, for materially improving their quality. It is, therefore, only in localities where this lower chalk can be obtained, that the above method of improvement can be with any material advantage adopted. This is proved by the practice at Sudbury, in Suffolk, which rests upon the upper beds, where it is found to be more profitable to import the lower chalk from Kent, to lay upon these lands, than to dress them with any of the chalks (only upper beds) which are immediately within their reach.*

6°. *Green Sand.*	500 *ft.*	The upper beds consist of layers of a greenish sand or sand-stone, often chalky. The gault is a solid compact mass of an impervious blue clay, sometimes marly. The lower green sand contains a series of ochrey resting on a
a Upper,	100.	
——— *b* Gault,	150.	
——— *c* Lower,	250.	

* A rigorous chemical analysis of characteristic specimens of these two chalks might lead to interesting results.

series of greenish sandy strata. The whole of these beds are in many places full of fossils.

EXTENT.—The Green Sand forms a narrow border round the whole of the northern and western edge of the chalk, except in Yorkshire, where it has not as yet been anywhere discovered at the surface. It skirts also the southern edge of the chalk in Surrey and Kent, and its eastern boundary in Hampshire, where it attains a breadth of eight or ten miles. It forms likewise the southern portion of the Isle of Wight.

SOIL.—The upper beds, which are the greenest and most chalky, form an open friable soil, easily worked, and of the most productive character. It consists in general of an exceedingly fine sand, mixed with more or less of clay and calcareous matter (see analysis, p. 234), coloured by greenish grains. It is rich and productive of every species of crop, and the peculiar richness of this soil has been remarked not only in England but also in the United States of North America. In some parts of Bedfordshire the soils of this formation form the most productive garden lands in the kingdom. In other localities, again, where the soil is formed from layers of black or of white silvery sand, it produces naturally nothing but heath.

The impervious gault clay forms in Cambridge and Huntingdon "a thin, cold clay soil, which, when wet, becomes as sticky as glue, is most expensive to cultivate as arable land, and naturally produces a poor, coarse pasture." Much of this tract, though unenclosed, is yet generally in arable culture, under two crops and a naked fallow—the enclosed parts are chiefly in pasture, and yield a rich herbage.

The lower green-sand presents itself over a comparatively small surface, is in some localities (Sussex) laden with iron ochre, and is there naturally unproductive.

B.—OOLITIC SYSTEM.

7°. *Wealden.* 950 *ft.*
——— *a* Weald Clay, 300.
——— *b* Hastings Sand, 400.
——— *c* Purbeck lime-stone, 250.

The upper part consists of a fresh-water deposit of brown, blue, or fawn-coloured clay, often marly and almost always close and impervious to water. Beneath this are the iron or ochrey Hastings sands, which again rest upon the Purbeck beds of alternate fresh-water lime-stones and marls.

EXTENT.—The Wealden rocks appear at the surface only in Sussex and Kent, of which they form the entire central portion.

SOIL.—The soil formed from the Weald Clay is fine grained and unctuous—often pale coloured, and containing much fine grained siliceous sand. It forms a paste which dries and hardens almost like a brick, so that the roots of plants cannot penetrate it. From the expense of cultivating such land, much of it is in wood (Tilgate Forest), and some is in poor wet pasture. On the whole of this tract, therefore, there is much room for improvement. The Hastings sands produce a poor brown sandy loam which naturally yields only heath and brush-wood. Much of this soil is in pasture, but, under proper cultivation, it yields good crops of all kinds. Where the ruins of the Purbeck marls are intermixed with it, the soil is of a superior quality.

8°. *Upper Oolite.* 600 *ft.*
a Portland Beds, 100.
b Kimmeridge Clay, 500.

The upper part of this formation consists of the oolite* limestones and calcareous sand-stones long worked at Portland—the lower of the blue slaty

* So named because they consist of small *egg*-shaped granules, like the roe of a fish.

or greyish, often calcareous and bituminous beds of the Kimmeridge clay.

EXTENT.—The Upper Oolite runs north-east along the northern edge of the green sand, from the western extremity of Dorset to the extreme north of Norfolk. It is in general only 2 or 3 miles, but in a few places expands to 6 or 8 miles in breadth. It appears again on the western edge of the green sand in Lincolnshire, and in Yorkshire forms a stripe 5 or 6 miles in breadth, which crosses the country from Helmsley to Filey Bay. In the Isle of Portland also it is found, and it stretches in a narrow stripe along part of the south coast of Dorset.

SOIL.—The soil from the Portland rocks, in consequence of the prevalence of siliceous and the absence of clayey matter, produces naturally, or when laid down to grass, only a poor and benty herbage. Its loose and sandy nature makes it also very cheap to work, and hence it is chiefly in arable culture. It is easily affected by drought, but in damp seasons it produces abundant crops —especially in those parts where the soil is naturally mixed with the detritus of the over-lying Hastings sand, and of the calcareous Purbeck beds.

The Kimmeridge clay forms a tough, greyish, impervious, often however very calcareous soil and subsoil. From the difficulty of working it, much of the surface over which this formation extends is laid down to grass, and the old pasture land affords excellent herbage. The celebrated pasture lands of the vale of North Wilts rests partly on this clay. The relative thicknesses of the Portland beds and the Kimmeridge clay will readily account for the fact of this clay being spread over by far the greatest part of the area occupied by this formation. In Yorkshire, clay of a great thickness is the only member of this series that has hitherto been observed. On this, as well as on the subjacent Oxford clay, the judicious investment of capital might produce a much greater annual breadth of corn.

9°. *Middle Oolite.* 500 *ft.*

Upper Calcareous Grit,	100.
Coral Rag,	
Calcareous Grit,	
Oxford Clay,	400.
Kelloways Rock,	
Blue Clay,	

The uppermost bed in this formation is a sand-stone containing a considerable quantity of lime—next is a coralline lime-stone (coral rag) resting upon other sand-stones, which contain much lime in their upper and little or none in their lower beds. Below these is an enormous deposit of adhesive tenacious dark blue clay, frequently calcareous and bituminous, and towards the lower part containing irregular beds of sand-stones and lime-stones (Kelloways rock) beneath which the clay again recurs.

EXTENT.—The middle adjoins the upper oolite on the north and west—accompanying it from the extremity of Dorset, into Wilts, Oxford, Huntingdon, Lincolnshire, and Yorkshire. Until it reaches Huntingdon, it rarely exceeds 6 or 8 miles in width, but in this county and in Lincoln it expands to a width of nearly 20 miles. In Yorkshire it nearly surrounds the upper oolite, and on the northern border of the latter formation attains a width from north to south of 6 or 8 miles.

SOIL.—The higher beds of both the upper and lower calcareous grits produce good land. They contain lime intermingled with the other materials of the siliceous sand-stone. The upper calcareous grits are no doubt improved by their proximity to the Kimmeridge clay above them, while the lower calcareous grit is in like manner benefitted by the lime of the super-incumbent coral rag. The under beds of both groups are the more gritty, and form a poor, barren, almost worthless soil, much of which in Yorkshire is still unreclaimed. Upon the hills of the coral rag itself occurs the best pasture which is met with

in that part of the North Riding of Yorkshire through which this formation extends.

The Oxford clay, which is by far the most important member of this formation, and forms the surface over by far the largest portion of the area occupied by it—produces a close, heavy, compact clay soil, difficult to work, and which is one of the most expensive of all the clays to cultivate. This is especially the case in Bedford, Huntingdon, Northampton, and Lincoln, in which counties, nevertheless, a considerable extent of it is under the plough. In Wilts, Oxford, and Gloucester, it is chiefly in pasture, and as over these districts it assumes the character rather of a clayey loam, the herbage is thick and luxuriant. The impervious nature of this clay has caused the stagnation of water upon its lower lying portions, the consequent accumulation of vegetable matter, and the formation of bogs. The extensive fens of Lincoln, Northampton, Huntingdon, Cambridge, and Norfolk, rest upon the Oxford clay. This tract of fenny country is 70 miles in length, and about 10 in average breadth. When drained and covered with the clay from beneath, it is capable of being converted into a most productive soil. In Lincolnshire, there are about a million acres of fen, which have their drainage into the Wash, about 50,000 of which are at present irreclaimable, on account of the state of the outlet.

In the neighbourhood of the Kelloways rock the clay becomes more loamy and less difficult to work.

Both in Yorkshire and in the southern districts, the Oxford clay is found to favour the growth of the oak, and hence it is often distinguished by the name of the *oak tree* clay.

10°.	*Inferior Oolite.*	600 *ft.*
——	*a* Cornbrash,	30.
——	*b* Forest Marble,	50.
——	*c* Bradford Clay,	50.
——	*d* Bath Oolite,	130.
——	*e* Fuller's Earth,	140.
——	*f* Inferior Oolite,	200.
——	*g* Calcareous Sand,	

Thin, impure, rubbly beds of shelly lime-stone form the upper part of this series. These rest upon alternate beds of oolitic shelly lime-stone and sandstone, more or less calcareous, having partings of clay; these again upon beds of blue marly clay, immediately under which are the thick beds of the light-coloured oolite lime-stone of Bath. Beneath these follow other beds of blue clay, with Fuller's earth, based upon another oolitic lime-stone, which is followed by slightly calcareous sands.

Extent.—This formation commences also at the south-western extremity of Dorset, and runs north-east, swelling out, here and there, and in Gloucester, Oxford, and Northampton attaining a width of 15 to 20 miles. It occupies nearly the whole of these three counties, covers almost the entire area of Rutland, a large portion of the north-east of Leicester, and then, in a narrow stripe, stretches north through Lincoln, and disappears at the Humber. It appears again in the North Riding of Yorkshire, skirting the outer edge of the middle oolite, on the north of which it attains a breadth of 15 miles, and stretches across, with little interruption, from near Thirsk to the North sea. A small patch of it appears farther north, on the south-eastern coast of Sutherland, and on the east and south of the Isle of Sky.

Soil.—It will be understood from what has been already stated in reference to other formations, that one which contains so many different rocks, as this does, must also present many diversities of soil. Where the upper beds come to the surface, the clay-partings give the character to the soil—forming a calcareous clay, which, when dry or drained, is of good quality. In other places it forms a close adhesive clay, which is naturally almost sterile. The Bath oolite weathers and crumbles readily. The soil upon it is thin, loose, and dry. The rock is full of vertical fissures, which carry off the water and drain its surface.

When free from fragments of the rock, the soil is often close and impervious, and, though of a brown colour, deep, and apparently of good quality, it is really worthless, or, as the farmers call it, *dead and sleepy*. Most of this land, however, is in arable cultivation. The heavy soils, which rest on the clay containing Fuller's earth, are chiefly in pasture.

The inferior oolite varies much in its character, containing, in some places, much lime-stone, while in others, as in Yorkshire, it forms a thick mass of sand-stones and clays, with occasional thin beds of coal. In Gloucester, Oxford, Northampton, and Rutland, these lower beds form a tract of land about 12 miles in width. The soil is generally soft, sandy, micaceous, of a brown colour, and of a good fertile quality. It is deep, contains many fragments of the subjacent rock, is porous, and easily worked. Where the sand-stones prevail, it is of inferior quality. In these counties it is principally enclosed, and in arable culture, the sides of the oolitic hills and the clayey portions being in pasture. In Yorkshire, much of the unproductive moor land of the North Riding rests upon this formation. Nearly all the arable land in the county of Sutherland rests on the narrow stripe of the lower oolite rocks which occurs on its south-east coast. The debris of these rocks has formed a loamy soil, which, when well limed, produces heavy crops of turnips.

11°. *Lias.* 500 *to* 1000 *ft.* This great deposit consists chiefly of an accumulation of beds of blue clay, more or less indurated—interrupted in various places by beds of marl, and of blue, more or less earthy, lime-stones, which especially abound in the lower part of the series. The whole is full of shells, and of the remains of large extinct animals.

EXTENT.—Wherever the lower oolites are to be traced in England, the lias is seen coming up to the surface on its northern or western edge, pursuing an exceedingly tortuous north-eastern course, throwing out in its course many arms (outliers), and varying in breadth from 2 to 6 or 10 miles. It may be traced from the mouth of the Tees, in Yorkshire, to Lyme Regis, in Dorset, the continuity being broken only by the coal field of Somerset. In Scotland and Ireland no traces of this formation have yet been detected.

SOIL.—Throughout the whole of this formation the soil is a blue clay, more or less sandy, calcareous, and tenacious. Where the lime or sand prevails the soil is more open, and becomes a loam; where they are less abundant, it is often a cold, blue, unproductive, wet clay. This latter, indeed, may be given as the natural character of the entire formation. Where it rests upon a gravelly or open subsoil, or contains a large quantity of vegetable matter, it may be cultivated to advantage, and it is found especially to produce good herbage. In all situations, it is an expensive soil to work, and hence by far the greater portion of it is in old pasture. The celebrated dairy districts of Somerset, Gloucester, Warwick, and Leicester, rest for the most part on the lias, as does also much of the best grazing and pasture land in Nottingham and Yorkshire. Through the long lapse of time an artificial soil has been produced on the undisturbed surface of these clay districts, which is peculiarly propitious to the growth of grass. With skilful drainage and judicious culture, it is capable of producing heavy crops of wheat.

C.—NEW RED SAND-STONE SYSTEM.

12°. *Upper and Lower Red Sand-stones.* 500 *ft.* The upper and lower red sand-stones consist of alternate layers of sand, sand-stones, and marls sometimes colourless, but generally of a red colour—sprinkled in the upper series with frequent green

spots. The lower beds are sometimes full of rolled pebbles. Few of the sand-stones of this formation are sufficiently hard to form building stones—many of the layers consist of loose friable sand, and the marls universally decay and crumble to a fine red powder under the influence of the weather.

Extent.—The new red sand-stone extends over a larger portion of the surface of England than any other formation. It commences at Torbay, in the south of Devon, runs north-east into Somersetshire; from Bristol ascends both sides of the Severn, accompanies it into the vale of Gloucester, stretches along the base of the Malvern hills, and north of the city of Worcester expands into a gently undulating plain, nearly 80 miles in width at its broadest part, comprehending nearly the whole of the counties of Warwick and Stafford and the greater part of that of Leicester. From this central plain it parts into two divisions. One of these runs west over the whole of Cheshire—(in which county it contains salt springs and mines of rock salt)—the western part of Flint, and on the south-west surrounds the county of Lancashire. It is there interrupted by the rising of the older rocks in Westmoreland, but re-appears in the eastern corner of this county, runs north-west through Cumberland, forming the plain of Carlisle—and thence round and across the Solway Frith till it finally disappears about 20 miles north of Dumfries. The other arm, proceeding from the towns of Derby and Nottingham, runs due north through Nottingham and the centre of Yorkshire, skirting the outer edge of the lias, and finally disappears in the county of Durham to the north of the river Tees. The southern portion of this arm has a width of 20 to 30 miles, until it reaches the neighbourhood of Knaresborough, where it suddenly contracts to 6 or 8, and does not again expand to more than 10 or 12 miles.

North of Dumfries-shire these rocks are not known to occur in our island. In the north-east of Ireland they form a stripe of land a few miles in width, running from Lough Foyle to Lough Neagh, and thence, with slight interruptions, to the south of Belfast.

Soil.—These rocks, by their decay, almost always produce a deep red soil. Where the red clay and marl predominate, this soil is a red clay or clayey loam of the richest quality, capable of producing almost every crop, and remarkable therefore for its fertility. It is chiefly in arable culture, because of the comparative ease with which it is worked, but the meadows are rich, and produce good herbage. Where the rocks are more sandy, and contain few marly bands, the soil produced is poorer, yet generally forms a good sandy loam, suitable for turnips and barley.

In Devonshire, as in the vale of Taunton and other localities, where the lias and the red sand-stone adjoin each other, or run side by side, the difference in the fertility and general productiveness of the two tracts is very striking. On the former, as already observed, good old grass land is seen, but the arable land on the latter produces the richest and most luxuriant crops to be seen on any soil in the kingdom. In this county, and in Somerset, the only manure it seems to require is lime, on every repetition of which it is said to produce increased crops. The same remarks as to its comparative fertility, apply with more or less force to the whole of the large area occupied by this formation in our island —wherever the soil has been chiefly formed by the decomposition of the rock on which it rests. In some localities (Dumfries-shire) the *micaceous*, marly rock is dug up, and, after being crumbled by exposure to a winter's frost, is laid on with advantage as a top-dressing to grass and other lands.

In the south of Lancashire, and along its western coast, and on the shores of the Solway, in Dumfries-shire, a great breadth of this formation is covered with peat.

13°. *Magnesian Lime-stone.* The magnesian lime-stone is generally of a yellow, sometimes of a grey, colour. In the upper part it occasionally presents itself in thin beds, which crumble more readily when exposed to the air. In some places, also, it assumes a marly character, forming masses which are soft and friable; in general, however, it is in thick beds, hard and compact enough to be used for a building stone or for mending the roads. The quantity of carbonate of magnesia it contains varies from 1 to 45 per cent. It is in the north of England generally traversed by vertical fissures, which render the surface dry, and make water in many places difficult to be attained.

EXTENT.—The *magnesian lime-stone* stretches in an almost unbroken line nearly due north from the city of Nottingham to the mouth of the river Tyne. It is in general only a few miles in width, its principal expansion being in the county of Durham, where it attains a breadth of 8 or 10 miles.

SOIL.—It forms, for the most part, a hilly country, covered by a reddish brown soil, often thin, light and poor, where it rests immediately on the native rock—producing indifferent herbage when laid down to grass, but under skilful management capable of yielding average crops of turnips and barley. In the eastern part of the county of Durham tracts of the poorest land rest upon this rock, but as this formation is for the most part covered with deep accumulations of transported materials—the quality of the soil is in very many places more dependent upon the character of this superficial covering than upon the nature of the rock beneath.

During the slow degradation of this rock, the rains gradually wash out great part of the magnesia it contains, so that it seldom happens that the soil formed from it, though resting on the parent rock, contains so mnch magnesia as to be necessarily hurtful to vegetation.

D.—CARBONIFEROUS SYSTEM.

14°. *Coal Measures.* 300 *ft.* Consisting of alternate beds of indurated bluish-black clay (coal shale), of siliceous sand-stone generally grey in colour and containing imbedded plants, and of coal of various qualities and degrees of thickness. Beds of lime-stone rarely appear in this formation till we approach the lowest part of the series.

EXTENT.—Fortunately for the mineral resources of Great Britain, the coal measures occupy a large area in our island. Most of the districts in which they occur are so well known as to require only to be indicated. The south Welsh coal-field occupies the south of Pembroke, nearly the whole of Glamorgan, and part of Monmouth-shire. In the north of Somerset are the coal measures of the Bristol field, which stretch also across the Severn into the forest of Dean. In the middle of the central plain of the new red sand-stone, lie the coal-fields of Ashby-de-la-Zouch, of Coventry, and Dudley, and on its western borders are those of Shropshire, Denbigh, and Flint (North Wales). To the north of this plain extends on the right the Yorkshire coal-field from Nottingham to Leeds, while on the left is the small coal-field of Newcastle-under-Line, and the broader Lancashire field which crosses the country from near Liverpool to Manchester. Almost the entire eastern half of the county of Durham, and

of the low country of Northumberland, is covered with these measures—but the largest area covered by these rocks is in that part of the low country of Scotland which extends in a north-easterly direction from the west coast of Ayrshire to the eastern coast of Fife. They there form a broad band, having an average breadth of 30 miles, interrupted often by trap or green-stone rocks, yet lying immediately beneath the loose superficial matter, over the largest portion of this extensive district. They do not occur further north in our island. In Ireland they form a tract of limited extent on the northern borders of the county of Monaghan—cover a much larger area in the south-east in Kilkenny and Queen's counties—and towards the mouth of the Shannon, spread on either bank over a large portion of the counties of Clare, Kerry, and Limerick.

Soil.—The soil produced by the degradation of the sand-stones and shales of the coal formation is universally of inferior quality. The black shales or schists form alone a cold, stiff, ungrateful clay. The sand-stones alone form thin, unproductive soils, or barren—almost naked—heaths. When the clay and sand are mixed a looser soil is produced, which, by heavy liming, by draining, and by skilful culture, may be rendered moderately productive. In the west of the counties of Durham and Northumberland, and on the higher edges of most of our coal fields, there are extensive tracts of this worthless sand-stone surface, and thousands of acres of the improveable cold clays of the shale beds. These latter soils appear very unpromising, and can only be rendered remuneratively productive in skilful hands. They present one of those cases in which the active exertions of zealous agriculturists, and the efforts of the friends of agriculture, might be expended with the promise of much benefit to the country.

15°. *Millstone Grit.* . 600 *ft.*

This formation consists in some localities of an entire mass of coarse sand-stone, of great thickness—in others of alternations of sand-stones and shales, resembling those of the coal-measures—while in others, again, lime-stones, more or less siliceous, are interposed among the sand-stones and shales.

Extent.—A large portion of Devonshire is covered with these rocks—they form also the high land which skirts to the north and west the coal-measures of Yorkshire, Lancashire, and Durham, and over which is the first ascent to the chain of mountains that run northward through these three counties. In Scotland, they have not been observed to lie immediately beneath any part of the surface. In the north of Ireland they cover a considerable area, stretching across the county of Leitrim between Sligo and Lough Erne.

Soil.—The soils resting upon, and formed from, these rocks are generally of a very inferior description. Where the sand-stones come to the surface, miles of naked rock appear; other tracts bear only heath, or, where the rains have only a partial outlet, accumulations of peat. The shale-beds, like those of the coal-measures, afford a cold, unproductive, yet not unimproveable soil—it is only where lime-stones occur among them that patches of healthy verdure are seen, and fields which are readily susceptible of profitable arable culture.

It is true, therefore, of this formation in general, that the high grounds form extensive tracts of moor-land. In the lower districts of country over which it extends, the soil generally rests not on the rocks themselves, but on superficial accumulations of transported materials, which are often of such a kind as to form a soil either productive in itself or capable of being rendered so by skilful cultivation.

16°. *Mountain Lime-stone.* } 800 *ft.*

In this formation, as its name implies, lime-stone is the predominating rock. It is generally hard, blue, and more or

less full of organic remains. In some localities, it occurs in beds of vast thickness—(Derby and Yorkshire)—while in others—(Northumberland)—it is divided into numerous layers, with interposed sand-stones and beds of shale, and occasional thin seams of coal.

EXTENT.—The greater portion of the counties of Derby and Northumberland are covered by this formation, and from the latter county it stretches along the west of Durham through Yorkshire as far as Preston, in Lancashire—forming the mountains of the well known Pennine chain, which throw out spurs to the east and west, and thus present on the map an irregular outline and varying breadth of country. In Scotland these rocks cover only a small portion of the county of Berwick, immediately on the Border; but in Ireland, almost the entire central part, forming upwards of one-half of the whole island, is occupied by the mountain lime-stone formation.

SOIL.—From the slowness with which this rock decays, many parts of it are quite naked; in others, it is covered with a thin light porous soil of a brown colour, which naturally produces a short but thick and sweet herbage. Much of the mountain lime-stone country, therefore, is in natural pasture.

Where the lime-stones are mixed or interstratified with shale beds, which decay more easily, a deeper soil is found, especially in the hollows and towards the bottom of the valleys. These are often stiff and naturally cold, but when well drained and limed produce excellent crops of every kind. In Northumberland, much of the mountain lime-stone country is still in moor-land, but the excellence of border farming is gradually rescuing one improveable spot after another from the hitherto unproductive waste. In Yorkshire and Devonshire also improvements are more or less extensively in progress, though, in all these districts, there are large tracts which can never be re-claimed.

E.—OLD RED SAND-STONE OR DEVONIAN SYSTEM.

17°.	*Old Red Sand-stone.*	500 *to* 10,000 *ft.*
——	Old Red Conglomerate.	
——	Corn-stone and Marls.	
——	Tile-stone.	

The upper part of this formation consists of red sand-stones and conglomerates (indurated sandy gravel), the middle of spotted, red and green, clayey marls, with irregular layers of hard, often impure and siliceous lime-stones (cornstones) likewise mottled, and the lowest of thin hard beds of siliceous sand-stones, sometimes calcareous, mottled, and splitting readily into thin flags (tile-stones).

EXTENT.—Though occasionally of vast thickness, the old red sand-stone does not occupy a very extensive area in our island. In the south of Pembroke it forms a tract of land on either side of the coal-field—surrounds on the north and east the coal-field of Glamorgan, and immediately north of this county covers a large area comprehending the greater portion of Brecknock and Hereford, and part of Monmouth. A small patch occurs in the Isle of Anglesey, and in the north-eastern corner of Westmoreland—but it does not again present itself till we reach the western flank of the Cheviot Hills. It there appears on either side of the Tweed, and extends over a portion of Berwick and Roxburgh to the base of the Lammermuirs. On the north of the same hills it again presents itself, and stretching to the south-west, forms a considerable tract of country in the counties of Haddington and Lanark. On the north of the great Scottish coal-field it forms a broad band, which runs completely across the island in a south-western direction along the foot of the Grampians, from Stonehaven to

the Firth of Clyde, is to be discovered in the Island of Arran, and at the Mull of Cantire, and—along the prolongation of the same line—at various places on the northern flank of the great mountain lime-stone formation of Ireland, and especially in the counties of Tyrone, Fermanagh, and Monaghan. In the north of Scotland, it lines either shore of the Moray Firth, skirts the coast towards Caithness, where it covers nearly the whole county, and still further north, forms the entire surface of the Shetland Islands. Along the north-western coast, it also appears in detached patches till we reach the southern extremity of the Isle of Sky.

In Ireland, it occurs also on the extreme southern edge of the mountain lime-stone, in Waterford and the neighbouring counties—and in the middle of this formation on the upper waters of the Shannon, in the south of Mayo, and round the base of the slate mountains of Tipperary.

Soil.—The soil on the old red sand-stone admits of very nearly the same variations as on the new red sand-stone formation. Where it is formed, as in parts of Pembroke, from the upper sand-stones and conglomerates, it is either worthless or it produces a poor hungry soil, "which eats all the manure, and drinks all the water." These upper rocks are sometimes so siliceous as to be almost destitute both of lime and clay—in such cases, the soils they form are almost valueless.

The marly beds and lime-stones of the second division, yield warm and rich soils—such as the mellow lands of Herefordshire, and the best in Brecknock and Pembroke shires. The soil in every district varies according as the partings of marl are more or less numerous. These easily crumble, and where they abound form a rich stiff wheat soil—like that of East Lothian and parts of Berwickshire;—where they are less frequent the soil is lighter and produces excellent turnips and barley. Where the subsoil is porous, this land is peculiarly favourable to the growth of fruit trees.* The apple and the pear are largely grown in Hereford and the neighbouring counties, long celebrated for the cider and perry they produce.

The tile-stones reach the surface only on the northern and western edges of this formation in England. In Ayrshire, in Lanarkshire, in Ross-shire, and in Caithness, larger tracts of land rest on these lower beds. In all these districts rich corn lands are produced from the rocks of the middle series. The fertility of Strathmore in Perthshire, and of other vallies upon this formation, is well-known—Easter Ross and Murray have been called the granary of Scotland, and even in Caithness rich corn-bearing (oat) lands are not unfrequent. Yet in the immediate neighbourhood of these rich lands, tracts of tile-stone country occur, which are either covered with useless bog (Ayrshire and Lanarkshire), or with a thin covering of soil which is almost incapable of profitable culture. In this latter condition is the moor of Beauly on the Cromarthy Firth, an area of 50 square miles, which, till within a few years, lay as an unclaimed common—and in the county of Caithness still more extensive tracts.

In South Devon and part of Cornwall a very fertile district rests also on the middle series of these rocks. Instead of red sand-stones, however, the country there consists of green slates, more or less siliceous, of sand-stones and of lime-stones, which by their decay have formed a very productive soil. These rocks in the above counties abound in fossil remains, and it is chiefly for this reason that the term *Devonian* has been applied to the rocks of the old red sand-stone formation.

* The most loamy of these red soils of Hereford afford the finest crops of wheat and hops, and bear the most prolific apple and pear trees, whilst the whole region (eminently in the heavier clayey tracts) is renowned for the production of the sturdiest oaks, which so abound as to be styled the "weeds of Herefordshire." Thus, though this region contains no mines, the composition of its rocks is directly productive of its great agricultural wealth.—*Murchison*, Silurian System, I., p. 192.

III. Primary Strata.—In these rocks slates abound, and lime-stones are more rare. Organic remains are also less frequently met with than in the superior rocks. These remains belong all to extinct species, the greater part to extinct genera and families, and are frequently so wholly unlike to existing races that it is often difficult to trace any resemblance between the animals which now live and those which appear to have inhabited the waters of those ancient periods.

F.—Silurian System.

18°. *Upper Silurian.* 3800 *ft.*

1°. Ludlow formation.

a Upper Ludlow *b* Aymestry Lime-stone *c* Lower Ludlow	2000

2°. Wenlock formation.

a Lime-stone *b* Shale	1800

The upper Ludlow rocks consist of sand-stones more or less calcareous and argillaceous. These rest upon hard, somewhat crystalline, earthy lime-stones (Aymestry lime-stones.) The lower Ludlow rocks are masses of shale more free from lime and sand than the upper beds, and from the mode in which they decay into *mud* are locally known by the name of "mud-stones."

The Wenlock or Dudley formation consists in the upper part of a great thickness of lime-stone beds often argillaceous, and abounding in the remains of marine animals; and in the lower part of thick beds of a dull clayey shale —in its want of cohesion, and in its mode of decay, very much resembling the *mud-stones* of Ludlow.

Extent.—The principal seat of these rocks in our island is in the eastern counties of Wales, where they lie immediately beneath the surface over the eastern half of Radnor, and the north of Montgomery.

Soil.—The prevailing character of the soils upon these formations is derived from the shales and mud-stones—and from the earthy layers of the sand-stones and lime-stones which decay more readily than the purer masses of these rocks. The traveller is immediately struck in passing from the rich red marls and clays of the old red sand-stone in Hereford, on to the dark, almost black, soils of the upper and lower Ludlow rocks in Radnor, not merely by the change of colour, but by their obviously diminished value and productiveness. The upper Ludlow is crossed by many vertical cracks and fissures, and thus, though clayey, the soil which rests upon it is generally dry, and susceptible of cultivation.

Not so the *muddy* soils of the lower Ludlow and Wenlock rocks. They are generally more or less impervious to water, and being subject to the drainage of the upper beds, form cold and comparatively unmanageable tracts. It is only where the intermediate lime-stones (Aymestry and Wenlock lime-stones) come to the surface and mingle their debris with those of the upper and lower rocks, that the stiff clays become capable of bearing excellent crops of wheat. This fact, however, indicates the method by which the whole of these cold wet clays might be greatly improved. By perfect artificial drainage and copious limeing, the unproductive soils of the lower Ludlow and of the Wenlock shales might be converted into wheat lands more or less rich and fertile. It unfortunately happens, however, that in those districts of North and South Wales, where the dark grey or black "*rotchy*" land of the mud-stones prevails, lime is often so scarce, or has to be brought from so great a distance, as to render this means of improvement almost unattainable.

19°. *Lower Silurian.* 3700 *ft.*

Caradoc Sand-stones	2500
Llandeilo Flags	1200

The Caradoc beds consist of thick layers of sand-stone of various colours, resting upon, and covered by, and occasionally interstratified with, thin beds of impure lime-stone. The Llandeilo flags which lie beneath them consist of thin calcareous strata, in some localities alternating with sand-stones and shales.

EXTENT.—These rocks form patches of land in Shropshire and the north of Montgomery—and skirt the southern and eastern edge of Caermarthen. None of the Silurian rocks have yet been found to extend over any large portion of either Scotland or Ireland.

SOIL.—The Caradoc sand-stone, when free from lime, produces only a naked surface or a barren heath. The Llandeilo flags form a fertile and arable soil, as may be seen in the south of Caermarthen, where they are best developed, and especially on the banks of the Towey, which for many miles before it reaches the town of Caermarthen runs over this formation.

In this formation, as in every other we have yet studied, the soil changes immediately on the appearance of a new rock at the surface. The soil of the Wenlock shale is sometimes more sandy as it approaches the Caradoc beds, and on favourable slopes forms good arable land and sustains luxuriant woods, but where the Caradoc sand-stones reach the surface, a wild heath or poor wood-land stretches over the country, until passing over their edges we reach the lime-containing soils of the Llandeilo flags, when fertile arable lands and lofty trees again appear.*

G.—CAMBRIAN SYSTEM.

20°. *Upper & Lower Cambrian Rocks.*

These rocks, which are many thousand yards in thickness, consist chiefly of thin slates, often hard and cleaving readily, like roofing slates, occasionally intermingled with sandy and thin lime-stone beds. They contain few organic remains.

EXTENT.—These rocks cover the whole of Cornwall, part of North and South Devon, the western half of Wales, the entire centre of the Isle of Man, and a large part of Westmoreland and South Cumberland. In Scotland, they form a band between 30 and 40 miles in width, which crosses the island from the Mull of Galloway to St. Abbs Head. They form also a narrow stripe of land, which recrosses the island along the upper edge of the old red sand-stone from Stonehaven to the Isle of Bute, and, further north, spread over a considerable portion of Banffshire. In the south-west of Ireland they attain a great breadth, are narrower at Waterford, but form a broad band along the granite mountains from that city to Dublin. They extend over a large portion of the counties of Louth, Cavan, Monaghan, Armagh, and Down,—form a narrow stripe also along the coast of Antrim as far north as the Giant's Causeway,—and, in the interior of Ireland, re-appear in the mountainous district of Tipperary.

SOIL.—The predominance of slaty rocks in this formation imparts to the soils of the entire surface over which they extend one common clayey character. They generally form elevated tracts of country, as in Wales, Cumberland, Scotland, and Ireland, where the rigours of the climate combine with the frequent thinness and poverty of the soil to condemn extensive districts to worth-

* Such a passage from one formation to another is exhibited in the diagrams inserted in page 238.

less heath or to widely extended bogs. Yet the slate rocks themselves, especially when they happen to be calcareous, are capable of producing fertile soils. Such are found in the valleys, on the hill sides, and by the margins of the lakes that are often met with in the slate districts. More extensive stripes or bands of such productive land occur also at lower levels, as in the north of Devon, and in the south of Cornwall. In the latter county, the soils on the *hornblende slate* (which lies near the bottom of the slate series) are extremely fertile, exhibiting a striking contrast with those which are formed from the neighbouring Serpentine rocks, that extend over a large area immediately north of the Lizard (see p. 265.)

Where the clay-slate soils occur, therefore, however cold and stiff they may be, a favourable climate, drainage, if necessary, and lime, either naturally present, or artificially added, appear to be the first requisites to insure fertility.

The mode in which these rocks lie, or the degree of inclination which the beds exhibit, exercises an important influence upon the agricultural character of the soils that rest upon them. In the diagram inserted in page 238, the rocks (A) represent the highly inclined, often nearly vertical position, in which the slate rocks are most frequently found. The soil formed from them must, therefore, rest on the thin edges of the beds. Thus it happens in many localities that the rains carry down the soluble parts of the soil and of the manure within the partings of the slates—and hence the lands are hungry and unprofitable to work.

On the slopes of the clay slate hills of the Cambrian and Silurian systems, flourish the vineyards of the middle Rhine, the Moselle, and the Ahr.

H.—Mica-Slate and Gneiss Systems.

21°. *Mica-Slate, Gneiss Rock.* The upper of these formations consists of thin undulating layers of rock, consisting chiefly of quartz and mica, alternating occasionally with green (chlorite) slates, common clay-slates, quartz rock and hard crystalline limestones. The gneiss is a hard and solid rock of a similar nature, consisting of many thin layers distinctly visible, but firmly cemented, and as it were half-melted together.

Extent.—Two-thirds of Scotland, comprehending nearly the whole country north and west of the Grampians, consist of these rocks. In England there is only a small patch of mica slate about Bolt Head and Start Point in South Devon, and a somewhat larger in Anglesey; but in Ireland, nearly the whole of the counties of Donegal and Londonderry on the north, and a large portion of Mayo, Connaught, and Galway, on the west, are covered by rocks belonging to the mica slate system.

Soils.—These rocks are, in general, harder still than those of the Cambrian system, and still more impervious to water, when not highly inclined. They crumble slowly, therefore, and imperfectly, and hence are covered with thin soils, on which, where good natural drainage exists, a coarse herbage springs, and from which an occasional crop of corn may be reaped—but on which, where the water becomes stagnant, extensive heaths and bogs prevail. That they contain, when perfectly decomposed and mellowed, the materials of a fertile soil, is shown by the richness of many little patches of land, that occur in the sheltered valleys of the Highlands of Scotland, and by the margins of its many lakes. In general, however, the mica-slate and gneiss country is so elevated that not only does an ungenial climate assist its natural unproductiveness, but the frequent rains and rapid flowing rivers bear down to the bottoms of the vallies or forward to the sea, much of the finer matter produced by the decay of the rocks,—leaving only a poor, thin, sandy soil behind.

On these hard slate and gneiss rocks extensive pine forests in Sweden and Norway have long lived and died. In these countries it is customary in many places to burn down the wood, to strew the ashes over the thin soil, to harrow in the seed—to reap thus one or two harvests of rye, and to abandon it again to nature. A grove of beech first springs up, which is supplanted by an after-growth of pine, and finally disappears.

Such is a general description of the nature and order of succession of the stratified rocks, as they occur in Great Britain and Ireland—of the relative areas over which they severally appear at the surface—and of the kind of soils which they produce by their natural decay. The consideration of the facts above stated,* shows how very much the fertility of each district is dependent upon its geological structure—how much a previous knowledge of that structure is fitted to enlighten us in regard to the nature of the soils to be expected in any district—to explain anomalies also in regard to the unlike agricultural capabilities of soils apparently similar—to indicate to the purchaser where good or better lands are to be expected, and to the improver, whether the means of ameliorating his soil by limeing, by marling, or by other judicious admixture, are likely to be within his reach, and in what direction they are to be sought for. There still remain some important branches of this subject to which, at the risk of fatiguing you, it will be my duty briefly to draw your attention in the following lecture.

* For much of the practical information contained in this section, I have to express my obligations to the following works:—For the extreme southern counties, to De La Beche's *Geological Report on Cornwall and Devon;* and to a paper by Sir Charles Lemon, Bart., on the *Agricultural Produce of Cornwall;*—for Wales and the Border counties, to Murchison's *Silurian System;*—for the Midland counties of England, to Morton *on Soils*, a work I have in a previous note recommended to the attention of the reader; for Yorkshire, to a paper by Sir John Johnston, Bart., in the *Journal of the Royal Agricultural Society;*—and for the Old Red Sand-stone of the north of Scotland, to the very interesting little work of Mr. Miller on *The Old Red Sand-stone.* The reader would read the above section with much greater profit if he were previously to possess himself of Phillip's *Outline Map of the Geology of the British Islands.*

LECTURE XII.

Composition of the granitic rocks and of their constituent minerals—Cause and mode of their degradation—Soils derived from them—Superficial accumulations—Their influence upon the character of the soils—Organic constituents, ultimate chemical constitution, and physical properties of soils.

It has been stated in the preceding Lecture, (§ 6, p. 237), that the rocks which present themselves at the surface of the earth are of two kinds, distinguished by the terms *stratified* and *unstratified*. The former crumble away, in general, more rapidly than the latter, and form a variety of soils of which the agricultural characters and capabilities have been shortly explained. The unstratified or crystalline rocks form soils of so peculiar a character and possessing agricultural capabilities in general so different from those of the stratified rocks which occur in the same neighbourhood, and they, besides, cover so large and hitherto so unfruitful an area in our island, as to entitle them to a separate and somewhat detailed consideration.

§ 1. *Composition of the Granitic Rocks.*

The name of *Granite* is given by mineralogists to a rock consisting of a mixture more or less intimate of three simple minerals—*Quartz*, *Mica*, and *Felspar*. When Mica is wanting, and *Hornblende* occurs in its stead, the rock is distinguished by the name of *Syenite*. This mineralogical distinction is often neglected by the geologist, who describes large tracts of country as covered by granitic rocks, though there may be many hills or mountains of syenite. In a geological sense, the distinction is often of little consequence; in relation to agriculture, however, the distinction between a granite and a syenite is of considerable importance.

The minerals of which these rocks consist are mixed together in very variable proportions. Sometimes the quartz predominates, so as to constitute two-thirds or three-fourths of the whole rock, sometimes both mica and quartz are present in such small quantity as to form what is then called a felspar rock. The mica rarely exceeds one-sixth of the whole, while the hornblende of the syenites sometimes forms nearly one half of the entire rock. These differences also are often overlooked by the geologist—though they necessarily produce important differences in the composition and agricultural characters of the soils derived from the crystalline rocks.

A few other minerals occur occasionally among the granitic rocks, in sufficient quantity to affect the composition of the soils to which they give rise. Among these, the different varieties of tourmaline are in many places abundant. Thus the *schorl* rock of Cornwall consists of quartz and schorl (a variety of tourmaline), while crystals of schorl are so frequently found in the granites of Devon, Cornwall, and the

Scilly Isles, as to be considered characteristic of a very large portion of them (Dr. Boase).

These rocks decay with very different degrees of rapidity—according to the proportions in which the several minerals are present in them, and to the peculiar state of hardness or aggregation in which they happen to occur. Both the mode of their decay, however, and the circumstances under which it takes place, as well as the character and composition of the soils formed from them, are materially dependent upon the composition of the several minerals of which the rocks consist. This composition, therefore, it will be necessary to exhibit.

1°. *Quartz* has already been described (p. 206), as a variety of silica—the substance of flints, and of siliceous sands and sand-stones. In granite, it often occurs in the form of rock crystal, but it is more frequently disseminated in small particles throughout the rocky mass. It is hard enough to scratch glass.

2°. *Felspar* is generally colourless, but is not unfrequently reddish or flesh-coloured. On the colour of the felspar they contain, that of the granites most frequently depends. Several varieties of this mineral are known to collectors. Besides the common felspar, however, it is only necessary to specify *Albite*, which, in appearance, closely resembles felspar, often takes its place in granite rocks, and in chemical constitution differs from it only in containing soda, while the common felspar contains potash. These two minerals are readily distinguished from quartz by their inferior hardness. They do not scratch glass, and, in general, may easily be scratched by the point of a knife.

They concist respectively of—

	Felspar.	Albite.
Silica	65·21	69·09
Alumina . . .	18·13	19·22
Potash	16·66	—
Soda	—	11·69
	100·00	100·00

It is to be observed, however, that these minerals do not generally occur in nature in a perfectly pure state—for though they do not essentially contain either lime, magnesia, or oxide of iron, they are seldom found without a small admixture of one or more of these substances. It is also found that while pure felspar contains only potash, and pure albite only soda, abundance of a kind of intermediate mineral occurs which contains both potash and soda. Such is the case with the felspar of the Siebengebirge, on the right bank of the Rhine (Berthier), and with those contained in the lavas of Vesuvius and the adjacent parts of Italy (Abich).

In these two minerals the silica is combined with the potash, soda, and alumina, forming certain compounds already described under the name of *silicates* (p. 207).

Felspar consists of a silicate of alumina combined with a *silicate of potash*. *Albite* of the same silicate of alumina combined with a *silicate of soda*.

3°. *Mica* generally occurs disseminated through the granite in small shining scales or plates, which, when extracted from the rock, split readily into numerous inconceivably thin layers. It sometimes occurs also

in large masses, and is of various colours—white, grey, brown, green, and black. It is soft and readily cut with a knife. The thin shining particles that occur in many sand-stones, and especially between the partings of the beds, and give them what is called a *micaceous* character, are only more or less weathered portions of this mineral.

Mica also consists of silicates, though its constitution is not always so simple as that of felspar. In some varieties magnesia is present, whilst in others it is almost wholly wanting, as is shewn by the following composition of two specimens from different localities.

	Potash. Mica.		Magnesian. Mica.
Silica	46·10		40·00
Alumina	31·60		12·67
Prot-Oxide of Iron .	8·65		19.03
Magnesia	—		15·70
Potash	8·39		5·61
Oxide of Magnesia .	1·40		0·63
Fluoric Acid . . .	1·12		2·10
Water	1·00	Titanic Acid	1·63
	98·26		97·37

If we neglect the three last substances, which are present only in small quantities, and recollect that the silica is *in combination* with all the other substances which stand beneath it, we see that these varieties of mica consist of a silicate of alumina, combined in the one with *silicate of iron* and *silicate of potash*, and in the other with *silicate of iron* and *silicate of magnesia*.

4°. *Hornblende* occurs of various colours, but that which forms a constituent of the syenites and of the basalts is of a dark green or brownish black colour, is often in regular crystals, and is readily distinguished from quartz and felspar by its colour, and from black mica by not splitting into thin layers, when heated in the flame of a candle. It consists of silicates of alumina, lime, magnesia, and oxide of iron, or per cent. of—

	Basaltic Hornblende.	Syenitic Hornblende.
Silica	42·24	45·69
Alumina	13·92	12·18
Lime	12·24	13·83
Magnesia	13·74	18·79
Prot-Oxide of Iron .	14·59	7·32
Oxide of Manganese	0·33	0·22
Fluoric Acid . . .	—	1·50
	97·06	99·53

A comparison of these two analyses shows that the proportions of magnesia and oxide of iron sometimes vary considerably, yet that the hornblendes still maintain the same general composition. They are remarkably distinguished from felspar *by the total absence of potash and soda, and by containing a large proportion of lime and magnesia.* From the potash-mica they are distinguished by the same chemical differences, and from the magnesian mica by containing lime to the amount of

$\frac{1}{4}$th part of their whole weight. Such differences must materially affect the constitution and agricultural capabilities of the soils formed from these several minerals, and they show the correctness of what I have previously stated to you—that mineralogical differences in rocks which may be neglected by the geologist, may be of great importance in explaining the appearances that present themselves to the philosophical agriculturist.

4°. *Schorl* usually occurs in the form of long black needles or prisms disseminated through the granitic rock, and generally (in Cornwall) at the outskirts of the granite, where it comes into contact with the slate rocks that surround it (De la Beche). It consists of a silicate of alumina in combination with silicates of iron and of soda or magnesia. Two varieties gave by analysis—

	Schorl from Devonshire.		Tourmaline from Sweden.
Silica,	35·20		37·65
Alumina,	35·50		33·46
Magnetic Oxide of Iron,	17·86		9·38
Magnesia,	0·70		10·98
Boracic Acid,	4·11		3·83
Soda,	2·09	Soda & potash,	2·53
Lime,	0·55		0·25
Oxide of Manganese,	0·43		—
	96·44		98·08

This mineral, according to these analyses, is characterised by containing from $\frac{1}{3}$ to $\frac{1}{10}$ of its weight of magnetic oxide of iron,* and sometimes $\frac{1}{10}$ of magnesia. The presence of Boracic acid† is also a remarkable character of this mineral, but as neither the presence of this substance in any soil, nor its effect upon vegetation, have hitherto been observed, we can form no opinion in regard to its importance in an agricultural point of view.

§ 2. *Of the degradation of the Granitic rocks, and of the soils formed from them.*

The granites, in general, are hard and durable rocks, and but little affected by the weather. The quartz they contain is scarcely acted upon at all by atmospheric agents, and in very many cases the felspar, mica, and hornblende yield with extreme slowness to their degrading power. It is chiefly to the *chemical decomposition* of the felspar that the wearing away of granite rocks is due, and the formation of a soil from their crumbling substance.

It has been stated that the felspars consist of a silicate of alumina in combination with silicates of potash or of soda. New these latter silicates are slowly decomposed by the carbonic acid of the air (see p. 207), which combines with the potash and soda, and forms *carbonates* of these alkalies. These carbonates are very soluble in water, and are, there-

* This oxide is composed of the *first* and *second* oxides of iron described in p. 219.

† Boracic acid occurs in combination with soda in the common *borax* of the shops. It combines with soda, potash, lime, &c., and forms *borates*. In the schorl it probably exists in such a state of combination.

fore, washed away by the first shower of rain that falls. The insoluble *silica* and the silicate of alumina are either left behind or are more slowly carried away by the rains in the form of a fine powder (a fine porcelain clay), and deposited in the valleys or borne into the rivers and lakes, —while the particles of quartz and mica, having lost their cement of felspar, fall asunder, and form a more or less siliceous sand.

Granite soils, therefore, on all *hanging grounds*,—on the sides and slopes of hills, that is—are poor and sandy, rarely containing a sufficient admixture of clay to enable them to support crops of corn—while at the bottoms of the hills, whether on flat or hollow grounds, they are composed, in great measure, of the fine clay which has resulted from the gradual decomposition of the felspar.

This clay consists chiefly of the silicate of alumina contained naturally in the felspar—it differs little, in short from that which has already been described (p. 161), under the name of pure or pipe clay, which is too stiff and intractable to be readily converted into a prolific soil.

It will readily be understood how such soils—decomposed felspar soils —must generally contain a considerable quantity of potash from the presence of minute particles of silicate of potash still undecomposed; and it will be as readily seen that they can contain little or no lime, since neither in felspar nor in mica has more than a trace of this earth been hitherto met with.

We have seen, however, that hornblende contains from $\frac{1}{4}$th to $\frac{1}{8}$th of its weight of lime, and as the same carbonic acid of the atmosphere which decomposes the felspar, decomposes the silicates of the hornblende also, it is clear that soils which are derived from the degradation of syenitic rocks, especially if the proportion of hornblende present in them be large, will contain lime as well as clay and silica. Thus consisting of a greater number of the elements of a fertile soil, they will be more easily rendered fruitful also—must naturally be more fruitful—than those which are formed from the granites, correctly so called. It is to the presence of this lime that the superior fertility of the soils derived from the hornblende slates of Cornwall, already adverted to (p. 255), is mainly to be ascribed.

Schorl, as above stated, contains much oxide of iron, and sometimes five or six per cent. of magnesia. It decomposes slowly, will give the soil a red colour, and though it contain only a trace of lime, yet the admixture of its constituents with those of the felspar *may possibly* ameliorate the quality of a soil formed from the decay of the felspar alone.

It thus appears that a knowledge of the constitution of the minerals of which the granites are composed, and of the proportions in which these minerals are mixed together in any locality, clearly indicates what the nature of the soils formed from them *must* be—an indication which perfectly accords with observation. The same knowledge, also, showing that such soils never have contained, and never can, naturally, include more than a trace of lime, will satisfy the improver, who believes the presence of lime to be almost necessary in a fertile soil, as to the first step to be taken in endeavouring to rescue a granitic soil from a state of nature—will explain to him the reason why the use of lime and of shell sand on such soils, should so long have been practised with the best ef

facts,—and will encourage him to persevere in a course of treatment which, while suggested by theory, is confirmed also by practice.

Extent of granitic rocks in Great Britain and Ireland.—In England, the only extensive tracts of granite occur in Cornwall and Devon, presenting themselves here and there in isolated patches from the Scilly Isles and the Land's End to Dartmoor in South Devon. In the latter locality, the granite rocks cover an area of about 400 square miles. Proceeding northward, various small *out-bursts** of granite appear in the Isle of Anglesey, in Westmoreland, and in Cumberland, and north of the Solway, in Kirkcudbright, it extends over 150 or 200 square miles;—but it is at the Grampian Hills that these rocks begin to be most extensively developed. With the exception, indeed, of the patches of old red sandstone already noticed, nearly the whole of Scotland, north of the Grampians—and of the western islands, excluding Skye and Mull, consists of granitic rocks.

In Ireland, a range of granite (the Wicklow) mountains runs south by west from Dublin to near New Ross—the same rock forms a considerable portion of the mountainous districts in the north-west of Donegal, and in the south of Galway—covers a less extensive area in Armagh, and presents itself in the form of an isolated patch in the county of Cavan.

Soils of the granitic rocks.—From what has been already stated in regard to the composition of granite, it is clear from theory that no generally uniform quality of soil can be expected to result from its decomposition, and this deduction is confirmed by practical observation. Where quartz is more abundant, or where the clay is washed out, the soil is poor, hungry, and unfruitful—such, generally, is its character on the more exposed slopes of the hills in the Western Isles, and in the north of Scotland.—[Macdonald's *Agricultural Survey of the Hebrides*, p. 26.] In the hollows and levels, where natural drainage exists, stiff clay soils prevail, which are often cold and unfruitful, but are capable of amelioration where the depth of earth is sufficient, by draining and abundant liming or marling. Where there is no natural drainage, vegetable matter accumulates, as we have seen to be the case on the surface of all impervious rocks—and bogs are formed. In the north of Scotland, and in Ireland, and in the high lands of Dartmoor (Devon), these are everywhere seen in such localities, and it is said that two-thirds of the Hebrides are covered with peat bogs more or less reclaimable.

In Cornwall and Devon, the granitic soils (*growan* soils, as they are there called) are observed to be more productive as the hills diminish in height. Thus Dartmoor is covered only with heath, coarse grass, and peat; while in the Scilly Isles the growan land produces good crops of wheat, potatoes, barley, and grass; and the same is observed at Moreton Hampstead, in Devon, where tolerable crops of barley are grown, and potatoes, which are highly esteemed in the Exeter market (De La Beche). No doubt the climate has something to do with these differences; but the less the elevation, and the consequent washing of the rains, the more of the clay will remain mixed with the siliceous sand;

* This expression is in some measure theoretical, and implies—what is the generally received opinion—that the granite rocks were forced up from beneath in a fluid state, like the lavas of existing volcanoes—that they, as well as the trap rocks, are, in short, only lavas of a more ancient date (see p. 237).

while in aid of both these causes, a small difference in the composition of its constituent minerals, often not to be detected by the eye, may materially affect the character of the granitic soils.

According to Dr. Paris, the presence of much mica deteriorates these soils; while that which is formed at the edges of the granite, when it comes in contact with the slate rocks, is of a more fertile quality. The latter remark, however, does not universally apply,—especially where the granite, as at the edges of Dartmoor, contains much schorl, (De La Beche)—and the presence of mica, in the richest soils of the red marl, would seem to imply that this mineral is fitted materially to promote the fertility of a soil in which the other earthy ingredients are properly adjusted.

The more elevated and thin granitic soils are said to be fitted for the growth of larch; the lower and deeper soils, which admit of the use of the plough, have been found to yield a three-fold return of corn by the use of lime alone.

§ 4. *Of the trap rocks, and the soils formed from them.*

Of the trap rocks there are several varieties, of which the most important are distinguished by the names of *Greenstone*, *Basalt*, and *Serpentine*.

The *Green-stones* consist of a mixture more or less intimate of felspar and hornblende, or of felspar and *augite*. They are distinguished from the granites by the absence of mica and quartz, and by the presence of the hornblende or augite, often in equal, and not unfrequently in greater quantity than the felspar. In the granites, the felspar and quartz together generally form upwards of $\frac{9}{10}$ of the whole mass.

Augite is a mineral having much resemblance to hornblende, and, like it, occurring of various colours. In the trap rocks it is usually of a dark green approaching to black. It generally contains much lime and oxide of iron in the state of silicates. The composition of two varieties compared with that of *basaltic* hornblende is as follows:—

	Black Augite from Sweden.	Augite from the lava of Vesuvius.	Basaltic Hornblende.
Silica	53·36	56·90	42·24
Lime	22·19	22·96	12·24
Magnesia	4·99	14·43	13·74
Prot-Oxide of Iron	17·38	6·25	14·59
Prot-Oxide of Manganese	0·09	—	0·33
Alumina	—	5·37	13·92
	98·01	99·91	97·06

The predominance of this mineral (augite) or of hornblende in the green-stone rocks must necessarily cause a very material difference in the nature of the soils produced from their decay, compared with those which are formed from the granitic rocks in which the felspars are the predominating mineral ingredient.

2°. *Basalt* consists of a mixture, in variable proportions, of augite, magnetic oxide of iron, and *zeolite*.* It differs in appearance from green-

* "*With or without felspar.*" In addition to augite, magnetic iron, and zeolite, many basalts contain also a considerable portion of certain *varieties* of felspar, especially of one to which the name of *nepheline* has been given.

stone, chiefly by the darkness of its colour, and by the minuteness of the particles of which it is composed, which, in general, cannot be distinguished by the naked eye.

Zeolite is a generic term applied to a great number of mineral species which occur in the basalts, and often intermixed with the green-stone rocks. *They differ from felspar in their greater solubility in acids, and by generally containing lime, where the latter contains potash or soda.*

It may be stated, indeed, as the most important agricultural distinction, between the granitic and the true* trap-rocks, that the latter abound in lime, while in the former, it is often entirely absent. If in a green-stone only one-fourth of its weight consist of augite, every 20 tons of the rock may contain one ton of lime. If in a basalt the augite and zeolite amount to only two-thirds of its weight, every nine tons may contain a ton of lime. The practical farmer cannot fail to conclude that a soil formed from such rocks must possess very different agricultural capabilities from the soils we have already described as being formed from the decomposition of the granites.

3°. *Serpentine* is a greenish yellow mineral, consisting of silica in combination with magnesia and a little iron, and *occasionally* a few pounds in the hundred of lime or alumina. The distinguishing ingredient is the magnesia, which generally approaches to 40 per cent. of the whole weight of the mineral. Rocks of serpentine are generally mixed with magnetic iron ore, and with portions of other minerals in greater or less abundance.

Extent of the trap rocks in the British Isles.—The serpentine rock occurs to any extent only in Cornwall, about the Lizard Point, where it covers an area of 50 square miles. The green-stones and basalts are only met with here and there in small patches, until we get so far north as the Cheviot Hills, which consist of these and other varieties of trap. It is in the low country of Scotland, however, intermixed with and surrounding the great-coal district of that part of the island, that the greatest breadth of trap is seen. It there stretches across the island in a south-west direction, and in detached masses, from the Friths of Tay and Forth to the island of Arran, covering an area of 800 or 1000 square miles. In the prolongation of the same line it re-appears in the north-east of Ireland, and extends over the whole of the county of Antrim and a small part of Londonderry and Armagh. In the most northerly portion of this tract the well-known columnar basalt of the Giants' Causeway occurs. On the west coast of Scotland the trap rocks cover nearly the whole of the islands of Mull and of Skye—to the west of the former of which islands lies Staffa with its celebrated basaltic caves.

Soil of the trap rocks.—The soil of the serpentine rocks at the Lizard is far from fertile, retaining the water and thus forming swamps and marshes. Even where a natural drainage exists it rarely produces good grass, or average crops of corn. It is remarkable for growing a peculiar, very beautiful heath—*erica vagans*—which so strictly limits itself to the serpentine soil as distinctly to mark the boundary by which the serpentine is separated from other rocks (De La Beche). From the

* *Serpentine* is not generally included among the *true* trap rocks: it is included among them here as it often is by geologists, because in many places, as at the Lizard, it occurs along with true green-stone.

composition of serpentine we might be led to suppose that the comparative barrenness of the soils formed from it is due to the large quantity of magnesia which this mineral contains; and this may, in some cases, be partly the cause. It would appear, however, that these soils often contain very little magnesia, the long action of the rains and of other agents having almost entirely removed it (see p. 209), and yet they still retain their barrenness. But they contain no lime, and, therefore, after draining, the first great step to take in order to improve such soils, is to give them a good dose of lime. How this step is to be followed up will depend upon the effect which this treatment is found to produce.

The soil of the green-stones is generally fertile, and it is more so in proportion as the hornblende or augite predominates—that is, generally, in proportion to the darkness of its colour.

In Cornwall and South Devon, where scattered masses of trap occur, consisting chiefly of hornblende and felspar, they "afford the most fertile soils of any in the district when their decomposition has taken place to a sufficient depth" (De La Beche). Wherever the trap rocks (locally *dun-stones*) are observed at the surface, "it is deemed a fortunate circumstance, being a certain indication of the fertility of the incumbent soils."—[Worgan's *View of the Agriculture of Cornwall*, p. 10.] The superior fertility of the neighbourhood of Penzance is owing to the presence of these rocks (Dr. Paris), and where their detritus has been mixed with that of other rocks—as with the worthless granite soils—it ameliorates and improves their quality.

The same general character is exhibited by the trappean soils of other districts of the island. The height of the Cheviot Hills renders the climate in many places unfavourable to arable culture, yet they produce the sweetest pasture,* while the low country around them has been largely benefitted by admixture with their crumbling fragments. The whole of that lowland tract of Scotland, over which these rocks extend—comprehending the counties of Ayr, Renfrew, Lanark, Linlithgow, Fife, and portions of Perth, Sterling, Edinburgh, and Haddington,—exhibit the fertile or fertilizing character of the decomposing green-stone. In Cornwall it is dug up as a marl and applied to the land, and in the neighbourhood of Haddington I have seen a farming tenant (*a leaseholder*) removing twelve inches of *trap* soil from the entire surface of a field, for the purpose of spreading a layer of an inch in depth over twelve times the area in another part of his farm. There can be no doubt that this mode of improvement is within the reach of many proprietors and farmers—especially along the southern borders of Perthshire, and near the more elevated of Ayr and Lanark.

To the north of Ireland, and to the Western Islands, the above remarks, with slight modifications, arising from local causes, will also apply. For example, where the surface is flat, and the rock impervious, water will collect and heaths and bogs will be produced, which only

* It is a singular fact observed here and there among the Cheviot Hills on the border, that where sheep are folded or pastured on hills of trap which are covered with delicate herbage, they are attacked by what is locally called the *pining ill*,—they pine away, become indolent, and are unwilling to move. The cure is to drive them to a neighbouring *sand-stone pasture*, where they become again active, and begin to thrive. The *pining* hills on each farm are well known, and the tenant has no hesitation in pointing to this and to that hill as those on which the sheep are sure to pine, if kept upon them only.

draining can remove. They apply also to other countries where trap rocks abound—the only fertile tracts of Abyssinia, for instance, being found in vallies and on mountain slopes, where the soil is composed of the detritus of trappean rocks (Dr. Rüppell.,

Yet there are exceptions to this general rule.

Where the felspar is largely predominant, the soil formed from the rock will partake more or less of the cold and barren character of the stiffer granitic soils. Such appears to be the case with some of the traps which occur in the border counties of England and Wales (Murchison).

In the Isle of Skye, again, a local peculiarity of a different kind obtains, the effect of which upon the soil is also to render it poor and unproductive. In that island the singularly beautiful ridge of the Cuchullen Hills consists of a variety of trap in which the augite so far predominates as to form nearly the whole of the mountain masses. But the augite in this case is a variety to which the name of *hypersthene* has been given, and which contains much magnesia and oxide of iron, but *scarcely a trace of either lime or alumina*. The rock is very hard, and decays with extreme slowness; yet however rapid its decay might be, it could never produce a fertile soil. We have seen that the serpentine and granite soils are essentially deficient in lime, but a hypersthene soil is in want both of lime and of clay. It would be still more difficult, therefore, to render the latter productive—even supposing, as in the case of the serpentine soils, that the magnesia of the hypersthene* were mostly washed away by the rains.

Thus we perceive how exactly the study of the composition of the different varieties of the trap rocks explains the observed differences in the quality of the soils derived from them. When the minerals they contain abound in lime, the soils they yield are fertile—when those minerals predominate in which lime is wanting, the soils are inferior, sometimes scarcely capable of cultivation. Again, the granites abound in potash; but except in the syenites they rarely contain lime, and their soils are generally poor. Let them be mixed with the trap soils, and they are enriched. This would seem fairly and clearly to imply that the fertility of the one is mainly due to the presence of lime, and the barrenness of the other to the absence of this earth.

On this subject I will only further add, that the more modern volcanic lavas which overspread Italy, Sicily, parts of France, Spain, and Germany, are closely related to the trap rocks in their general composition—and the fertility which overspreads thousands of square miles of decomposed lava streams and ejections of volcanic ashes in Italy and Sicily, is too well known to require any detailed description.

§ 5. *Of superficial accumulations of foreign materials, and of the means by which they have been transported.*

Abundant proof, I think, has now been advanced that a close relation

* The hypersthene of Skye has been found to consist of—

Silica	51·35	Prot-oxide of iron	33·92
Lime	1·34	Water	0·50
Magnesia	11·09		
			98·70

The composition probably varies in different parts of the rock, some containing more magnesia and less iron than is here represented.

generally exists between the soil and the rocks on which it rests, and that the geological structure of a country, as well as the chemical constitution of the minerals of which its several rocky masses consist, have a primary and fundamental influence upon the agricultural capabilities of its surface.

And yet I should be leading you into a serious error, were I to permit you to suppose that this intimate and direct relation is always to be observed—that in whatever district you may happen to be, you will find the soil taking its general character from the subjacent rocks—and that where the same rocks occur, similar soils are always to be expected. On the contrary, in very many localities the soil is totally different from that which would be produced by the degradation or decomposition of the rocks on which it rests. To infer, therefore, or to predict, that on a given spot, where, according to the geological map, red sand-stone for example prevails, a marly or other red sand-stone soil will necessarily be found—or that where the coal measures are observed, poor, ungrateful land must exist—would be to form or to state opinions which a visit to the several localities would in many instances show to be completely erroneous—and which would bring undeserved discredit upon geological science.

In such cases as these geology is not at fault. New conditions only have supervened which render the natural relation between soils and rocks in those places less simple, and consequently more obscure. Yet a further study of geological phenomena removes the obscurity—shows to what cause it is owing that in many districts the soil is such as could never have been formed from the subjacent rocks—again places the enlightened agriculturist in a condition to pronounce generally from what rocks his soils have been derived—generally also what their agricultural capabilities are likely to be, and by what mode of treatment those capabilities may be most fully developed.

Of the surface of Great Britain and Ireland it may indeed be truly said, that it exhibits extensive tracts in which the character of the soil is directly influenced by, and may be inferred from, the character and composition of the subjacent rock. To these districts the rules and observations contained in the preceding sections directly and clearly apply. But other extensive tracts also occur in which the character of the soil is independent of that of the rocks on which it immediately rests—the cause of this apparent difficulty we are now to consider.

1°. I have already had occasion to explain to you in what way all rocks crumble more or less rapidly, and give origin to soils of various kinds. Were the surfaces of rocks uniformly level, and that of every country flat, the crumbled materials would generally remain on the spots where they were formed. But as already shown in the diagrams, inserted in page 238, the rocks rarely lie in a horizontal position, but rest almost always more or less on their edges; and the surface in such a country as ours is often mountainous or hilly, and everywhere undulating. Hence the rains are continually washing off the finer particles from the higher, and bearing them to the lower grounds—and on occasions of great floods, vast quantities even of heavy materials are borne to great distances, and spread sometimes to a great depth and over a great extent of country—[witness the still recent floods in Morayshire.]

Thus the spoils of one rocky formation are borne from their native soil, and are strewed over the surface of other kinds of rock of a totally different character. The fragments of the granite, gneiss, and slate rocks of the high lands are scattered over the old red sand-stones which lie at a lower level—and those of the blue lime-stone mountains over the mill-stone grits, the coal measures, and the new red sand-stones, which stretch away from their feet.

2°. But the effects produced by this natural cause, though they may be judged of in kind, can never be estimated in degree by what we perceive in our own temperate climates—in our country of small rivers and gentle rains. How must such effects exceed in magnitude, in districts where,—as in the Ghauts, that separate the level land of the Malabar coast (the Concan) from the high table-land of the Deccan,—120 inches of rain occasionally fall in a single month, and 240 inches or 20 feet, on an average, every year from June to September! And to what vast distances must materials be transported by great rivers, such as the Mississippi, the River of Amazons, the Ganges, and the Indus, which maintain a course of thousands of miles, before they empty themselves into the sea? What necessary connection can the deposits of mud and sand which yearly collect at the mouths and in the places overflowed by the waters of these great rivers, have with the nature of the rocks on which these transported materials may happen to rest?

3°. But the constant motion of the waters of the sea washes down the cliffs on one coast, and carries away their ruins to be deposited, either in its own depths, or along other more sheltered shores. Hence sand banks accumulate—as in the centre of our own North Sea: or the land gains upon the water in one spot what it loses in another—as may be seen both on the shores of our own island, and on the opposite coasts of Germany and France.

What necessary relation can the soils thus gained from the sea have to the rocks on which they rest? Suppose the bottom of the North Sea to become dry land, what necessary mineral relation would then exist between the soils which would gradually be formed on its hundreds of square miles of sand-banks, and the rocks on which those sand-banks immediately repose?

4°. Again, the sea, in general, carries with it and deposits in its own bosom the finest particles of clay, lime, and other earthy matters, and leaves along its shores accumulations of fine siliceous sand. This sand, when dry, the sea winds bear before them and strew over the land, forming sand hills and downs, sometimes of considerable height and of great extent. Such are to be seen here and there, in our own islands, but on the Eastern shores of the Bay of Biscay, and on the coasts of Jutland,—both exposed to violent sea winds,—they occur over much larger areas. Before these winds the light sands are continually drifting, and, year by year, advance further and further into the country, gradually driving lakes before them, swallowing up forests and cultivated fields, with the houses of the cultivators, and burying alike the fertile soils and the rocks from which they were originally derived. [In the Landes, the advance of the downs is estimated at 66 to 70 feet every year.]

You have all read of the fearful sands of the African deserts, and of

their destructive march when the burning winds awaken. History tells of populous cities and fertile plains, where nothing but blown sands are now to be seen, and geology easily leads us back to still more remote periods, when the broad zones of sandy desert were but narrow stripes of blown sand along the shores of the sea, or beds of comparatively loose sand-stone, which here and there came to the surface, and which the winds have gradually removed from their original site, and wafted widely over the land.

Wherever these sand-drifts spread, it will also be clear to you, that there may be no necessary similarity between the loose materials on the surface and the kind of rock over which these materials are strewed.

5°. Along with these I shall mention only one other great agent by which loose materials are gradually transported to considerable distances.

It is observed in elevated countries, where the snow never entirely melts, and where glaciers or sheets of ice hang on the mountain sides,—descending towards the plains as the winter's cold comes on, and again retreating towards the mountain-tops at the approach of the summer's heat—that the edges of the glaciers bear before them into the valleys, and deposit along their edges, banks of conical ridges of sand and gravel (Moraines). These consist of the fragments of the rocky heights, worn and rounded by the friction of the sheets of ice beneath which they have descended from above, and from the edges of which they finally escape into the plain.

These ridges of sand and gravel accumulate till some more sudden thaw than usual, or greater summer's heat arrives, when they are more or less completely broken up by the rush of water that ensues, and are dispersed over the subjacent tracts of level land.

When the rocks are of a kind to rub down so fine as to form much mud as well as sand or gravel, the ridges are of a more clayey character. And where the edges of the glaciers descend to the borders of lakes or seas—as in the Tierra del Fuego—this mud is washed away and widely spread by the waters, while the gravel and sand remain nearer their original site; or, finally, when the ice actually overhangs the water, huge fragments break off now and then—loaded with masses of gravel and sand, or even with rocks of large size,—which fragments float away often to great distances and drop their stony burdens here and there, as they gradually melt and disappear.

To these facts, let it be added, that recent geological researches, of a very interesting kind, tend to show that nearly all the elevated tracts of country in the temperate regions of Europe and America—in our own island among other localities—have been covered with glaciers at a comparatively recent period, (geologically speaking,) and that these glaciers have gradually retreated step by step to their present altitudes, halting here for a time, and lingering there;—and we shall find reason to believe that traces of transported materials—moved from their original site by this agent also—are to be looked for on almost every geological formation.

And such the geological observer finds to be in reality the case.

§ 6. *Of the occurrence of such accumulations in Great Britain, and of their influence in modifying the character of the soil.*

Such accumulations, for example, present themselves over a large portion of our own island. Thus, in Devonshire, the chalk and green sand are so completely covered by gravels, consisting of the fragments of older rocks from the higher grounds, mixed with chalk-flints and chert, that nearly the whole of this tract possesses one common character of infertility, and is widely covered with downs of furze and heath (De La Beche.) In like manner the chalk, green sand, and plastic clay of a large portion of Norfolk and Suffolk, and of parts of the counties of Essex, Cambridge, Huntingdon, Bedford, Hertford, and Middlesex, are covered with till, (stiff unstratified clay,) containing large stones, (boulders,) or with gravels, in which are mixed fragments of rocks of various ages, which must have been brought from great distances, and perhaps from different directions (Lyell.) So over the great plain of the new red sand-stone, in the centre and west of England—in Lancashire, Cheshire, Shropshire, Staffordshire, and Worcestershire—drifted gravels of various kinds are widely spread. It may indeed be generally remarked, that over the bottoms of all our great vallies, such drifted fragments are commonly diffused—that upon our wider plains, they are here and there collected in great heaps—and that on the lower lands that border either shore of our island, extensive deposits of clay, sand, or gravel, not unfrequently cover to a great depth the subjacent rocks.

The practical agriculturist will be able to confirm this remark, in whatever district almost he may live, by facts which have come within his own knowledge and observation. I shall briefly explain, by way of illustration, the mode in which such accumulations of drifted matter overlie the eastern or lower half of the county of Durham.

The eastern half of the county of Durham reposes, to the north of the city of Durham, chiefly upon the coal measures, (sand-stones and shales;) to the south, chiefly on the magnesian lime-stone and the new-red sand-stone. These coal measures rise, here and there, into considerable elevations, as at Gateshead Fell near Newcastle, and Brandon Hill near Durham, where the rocks lie immediately beneath the surface, and are covered by comparatively little transported matter. The magnesian lime-stone, also, in many localities, starts up in the form of round hills or ridges, on which reposes only a poor thin soil, formed in great measure by the crumbling of the rock itself. Yet, generally speaking, this entire district is overspread with a thick sheet of drifted matter, consisting of clays, sands, and gravels.

This drift is made up of three separate layers, to be observed more or less distinctly in taking a general survey of the county, though there are few spots where they can all be seen reposing immediately one over the other.

1°. The upper layer consists of clays—on the higher grounds, poor, stiff, yellow—on the hill-sides and slopes of the valleys, often darker in colour—but almost everywhere full of rounded trap boulders* from a few

* In some parts of Northumberland these trap boulders are still more numerous. In the country which stretches between the north and south Tyne, the old grass fields are full of them. A friend of mine informs me that in ploughing out a nine-acre field on his estate in that district, there were dug out and carried off no less than 900 tons of such rolled stones great and small!

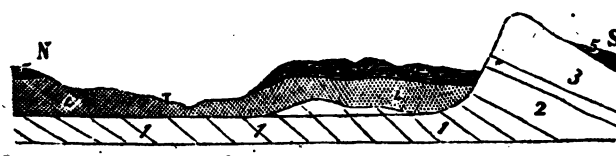
pounds to many tons in weight. These are generally dug up when they obstruct the plough, and are sold for mending the roads at about 5s. a ton. This clay varies in depth, from one or two, to fifty or sixty feet.

2°. Beneath the clay occurs an accumulation of fine, generally yellow, more rarely red, sand, intermixed with occasional layers and round hills of gravel—with frequent black streaks of rounded coal dust, and here and there with nests of rounded lumps of coal, from half an inch to five or six inches in diameter. This coal is sometimes so abundant as to be collected and sold for burning.

The gravels, where they overlie the coal measures, consist chiefly of rounded, and on the upper part occasionally of large angular masses of coal sand-stones—with here and there a fragment of trap, of mountain lime-stone, or of some of the older rocks to be met with in the mountainous districts towards the west. Over the magnesian lime-stone, however, in the south-eastern division of the county, towards the foot of the south-eastern slope of the magnesian lime-stone hills, the gravels which exhibit in some places (Wynyard) an irregular stratification, contain many rounded masses of magnesian lime-stone, and even of new-red sand-stone—the evident debris of adjacent rocks long ago broken up.

3°. The undermost layer which rests immediately upon the subjacer rocks consists of a stiff unstratified blue clay often full of trap boulders but containing also occasional large rounded masses of blue lime-stone —and smaller pebbles of quartz, of granite, and of the older slate rocks. In many localities this clay is wanting, and the sands or gravels rest immediately upon the carboniferous or magnesian lime-stone rocks—while in some tracts, both this and the upper clay appear to degenerate into a stony most unmanageable clayey gravel. I am not aware that the large whin (trap) boulders are ever met with in the beds of sand.

The following diagram exhibits the mode in which these drifted materials present themselves in the neighbourhood of the city of Durham. The cross (†) indicates very nearly the site of Durham on the banks of the river Wear.



No. 1 represents the coal measures.

2. The lower new-red sand-stone, here soft and pale yellow.

3. The magnesian lime-stone rising into a high escarpment from 3 to 6 miles south of the city.

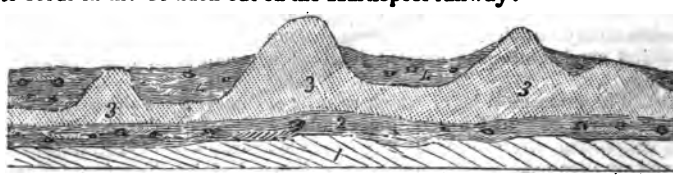
4. Yellow loose sand—with rolled sand-stones and coal-drift—occasionally stratified. It forms the numerous picturesque round hills in the neighbourhood of the city, and varies from a few feet to not less than 120 feet in thickness.

5 is the upper clay, with boulders. N indicates Framwellgate Moor, where it is only a few feet thick. At S, on the southern slope of the escarpment, it sometimes rests immediately on the rock as here re-

presented—in which case it is difficult to decide whether it should be considered as the under or the upper clay—though in other spots both sand and clay, or gravel and clay, present themselves.

It will at once occur to you from the inspection of this diagram, that the general character of the soil in the county of Durham, wherever such accumulations of drifted matter occur, is not to be judged from the nature of the rocks on which they are known to rest.

Another fact, not unworthy of your attention, is the rapid alternations of light and heavy soil, of sands or gravels and clays, which present themselves in the same district, I may say in the same farm, and often in the same field. This arises from the irregular thickness of the deposit of sand or gravel over which the upper clay rests. The surface of this sand is undulating, as if it had formed a country of round hills before the clay was deposited upon it. This appears in the following diagram, which represents the way in which the several layers are seen to occur in the Crindon cut on the Hartlepool railway:—



Here 1 is the magnesian lime-stone, not visible; 2, the under clay, with boulders; 3, the sand rising in round hills, and here and there piercing to the surface; and 4, the upper boulder clay.

In the county of Durham it is a very usual expression that the tops of the hills are light turnip soil—but that they *fall off to clay*. Both the meaning and the cause of this are explained by the above diagram.

Nor is this mode of occurrence rare among the alternate sands and clays of which the superficial accumulations in various parts of the country consist. Nearly the same circumstances give rise to the rapid changes so frequently observed in the character of the soil, as we pass from field to field, not in this county only, but in various other parts of our island.

§ 7. *How far these accumulations of drift interfere with the general deductions of Agricultural Geology.*

Thus it appears, that over the eastern half of the county of Durham, and over large portions of other counties, the soils are found to rest upon and to derive their character from accumulations of drifted materials more or less different in their nature from the rocks that lie beneath.

But in the preceding lecture I have endeavoured to show you that soils are derived from the rocks on which they rest, and to impress upon you the close general relation which exists between the *kind of rocks* of which a country is composed, and the *kind of soils* by which its surface is overspread.

How are these apparent contradictions to be reconciled? How is any

degree of order to be evolved out of this apparent confusion? Are the general indications of agricultural geology (Lecture xi., § 8,) still, in any degree, to be relied upon?

They are, and for the following, among other reasons:

1°. It is still *generally* true that where a considerable extent of country rests upon any known rock, the soil in that district derives its usual character from the nature of that rock. Thus though large portions of Cheshire and Lancashire are covered with drift, yet the soil of these counties, taken as a whole, has the general characters of the soils of the new-red sand-stone, which in that part of England is so largely developed.

2°. Where the drift overspreads any large area, it is found to become gradually mixed up with the fragments, large and small, of the rocks upon which it reposes. Thus in the neighbourhood of Durham, the round hills of sand and gravel with intermingled coal consist in great part of the ruins of the sand-stones of the country itself—while the clays, no doubt, are partly derived from the shale beds which occur intermingled with the sand-stones of the same coal measures. Hence the soils of the northern half of this county, in general, still partake of the usual qualities of those of the coal measures and mill-stone grit (pp. 249 and 250). In the western and higher part of the district they lie more immediately on the rocks from which they have been derived, while on the eastern half they rest on a mixture of the accumulated ruins of the same rocks, which have been transported by natural agents to a greater or less distance from their natural site.

It is true that there are mixed up with these many portions of other rocks brought from a still greater distance, but these bear but a small proportion to the entire mass, and hence have, generally speaking, but little influence in altering the mineral character of the whole.

3°. It may indeed be stated as generally true, that the greater proportion of the transported materials which lie upon any spot has been brought only a comparatively small distance. Thus the sands and gravels in the county of Durham—to the west of the magnesian lime-stone—consist chiefly of the fragments of the coal measures. East and south of the magnesian lime-stone escarpment (diagram, p. 271), they become mixed with rounded masses of this lime-stone. On the new-red sand-stone of the south-east of the county, they consist chiefly of magnesian lime-stone mixed with fragments of the red sand-stone—and on crossing the Tees, the debris of the lias hills begins to appear among them.

In countries, therefore, where drifted sands and gravels prevail on the surface, they generally consist of the fragments of rocks which lie at no great distance—generally towards the higher ground—the natural tendency being for the debris of one kind of rock, or of one formation, to *overlap* to a greater or less extent the surface of the adjoining rock or formation. By this overlapping, the *geographical* position of a given soil is removed to a greater or less distance beyond the line indicated by the *geological* position of the rocks from which it is derived. Thus, a coal measure soil may overspread part of the magnesian lime-stone—a red sand-stone soil may partially cover the lias, and so on—the general

characters and distinctions of the soil peculiar to each rock being still preserved beyond the spaces upon which they have been accidentally intermingled.

4°. To this, and to each of the other statements above made, there are many local exceptions. For instance, what is true of sands and gravels, will not so well apply to the fine mud of which many clays are formed. Once commit these to the water, and if it has any motion, they may be transported to very great distances from their original site. Rivers, lakes, and seas, are the agents by which these extensive diffusions are effected. The former produce what are called alluvial formations or deposits; which are generally rich in all the inorganic substances that plants require, and hence yield rich returns to the agricultural labourer. They are usually, however, distinguished, and their boundaries marked, by the geologist—so that the soils which repose upon them do not contradict any of the general deductions he is prepared to draw, in regard to the general agricultural capabilities of a country, from the kind of rocks of which it consists.

Thus though the occurrence of extensive fields of drift over various parts of almost every country, does throw some further difficulty over the researches of the agricultural geologist, and requires from him the application of greater skill and caution before he pronounce with certainty in regard to the agricultural capabilties of any spot before he visit it—yet it neither contradicts the general deductions of the geologist nor the special conclusions he would be entitled to draw in regard to the ability of any country, when rightly cultivated, to maintain in comfort a more or less numerous population. The *political economist* may still, by a survey of the geological map of a country, pronounce with some confidence to what degree the agricultural riches of that country might by industry and skill be brought—and which districts of an entire continent are fitted by nature to maintain the most abundant population. The intending *emigrant* may still, by the same means, say in what new land he is most likely to find a propitious soil on which to expend his labour—or such mineral resources as will best aid his agricultural pursuits;—while a careful study of the geological map of his own country will still enable the skilful and adventurous *farmer* to determine in what counties he will meet with soils that are suited to that kind of practice with which he is most familiar—or which are likely best to reward him for the application of the newest and most approved methods of culture.

Still there are some aids to this kind of knowledge yet wanting. We have *geological* maps of all our counties, in which the boundaries of the several rocky formations are more or less accurately pointed out, and from these maps, as we have seen, much valuable agricultural information may be fairly deduced. We have also *agricultural* maps of many counties, compiled with less care, and often with the aid of little geological knowledge, as that of Durham in Bailey's 'View of the Agriculture of the County of Durham,' published in 1810. But agriculture now requires geological maps of her own—which shall exhibit not only the limits of rocky formations, but also the nature and relative extent of the superficial deposits (drifts), on which the soils so often rest, and from which they are not unfrequently formed. These would afford a

sure basis on which to rest our opinions in regard to the agricultural capabilities of the several parts of a county in which, though the rocks are the same, the soils may be very different. To the study of these drifted materials, in connection with the action of ancient glaciers (p. 269), the attention of geologists is at present much directed, and from their labours agriculture will not fail to reap her share of practical benefit—the geological survey, also, so ably superintended by Mr. De La Beche, is collecting and recording much valuable information in regard to the agricultural geology of the southern counties—but it is not unworthy the consideration of our leading agricultural societies—whether some portion of their encouragement might not be beneficially directed to the preparation of agricultural maps, which should represent, by different colours, the agricultural capabilities of the several parts of each county, based upon a knowledge of the soils and sub-soils of each parish or township, and of the rocks, whether near or remote, from which they have been severally derived.

Before leaving this subject, I will call your attention to one practical application of this knowledge of the extensive prevalence of drifts, which is not without its value. Being acquainted with the nature of the rocks in a country, and with its physical geography—that is, which of these rocks form the hills, and which the valleys or plains—we can predict, in general, that the materials of the hills will be strewed to a greater or less distance over the lower grounds, and that these lower soils will thus be more or less altered in their mineral character. And when the debris of the hills is of a more fertile character than that of the rocks which form the plains, that the soils will be materially improved by this covering:—the soil of the mill-stone grit, for example, by the debris of the mountain lime-stone, or of a decayed green-stone or a basalt. On the other hand, where the higher rocks are more unfruitful, and the low lands are covered with sterile drifted sands brought down from the more elevated grounds—a knowledge of the nature of the subjacent rock may at once suggest the means of ameliorating and improving the unpromising surface-drift. Thus the loose sand of Norfolk is fertilized by the subjacent chalk marl; and even sterile heaths (Hounslow), on which nothing grew before, have, by this means, been made to produce luxuriant crops of every kind of grain.

§ 8. *Of superficial accumulations of Peat.*

Of superficial accumulations, that of peat is one which, in the United Kingdom, covers a very large area. In Ireland alone, the extent of bog is estimated at 2,800,000 acres. None of the drifted materials we have considered, therefore, would appear so likely to falsify the predictions of the geologist, who should judge of the soils of such a country from information in regard to the rocks alone on which they rest—from a geological map for example—as the occurrence of these peat bogs. Yet there are certain facts connected with the formation of peat, which place him in some measure on his guard in reference even to accumulations of vegetable matter such as these.

1°. There is a certain range of temperature within which alone peat seems capable of being produced. Thus, at the level of the sea, it is never found nearer the equator than between the 40° and 45° of latitude;

while its limit towards the poles appears to be within the 60th degree. It is a product, therefore, chiefly of the temperate regions.

Still, on the equator itself, at a sufficient altitude above the sea, the temperature may be cool enough to permit the growth of peat. Hence, though on the plains of Italy no peat is formed, yet, on the higher Appenines, it may be here and there met with, among the marshy basins, and on the undrained mountain sides.

99. The occurrence of stagnant water is necessary for the production of peat. Hence, on impervious beds of clay, through which the rains and springs can find no outlet, the formation of peat may be expected. Thus on the Oxford clay repose the fens of Lincoln, Cambridge and Huntingdon (p. 245). On impervious rocks also, peat bogs form for a similar reason. The new-red sand-stone is occasionally thus impervious, and on it, among other examples, repose the Chat moss, the tract of peat, mostly in cultivation, which lies west of a line drawn between Liverpool and Preston, and the large extent of boggy country which stretches round the head of the Solway Firth. On the old red sandstone, the mountain lime-stone, the slate, and the granite rocks, much peat occurs, and it is on these latter formations that the extensive bogs of Scotland and Ireland chiefly rest.

But though these two facts are of some value to the politician and to the geologist in indicating in what countries and on what formations peat may be expected to occur, yet they are of comparatively little importance to the practical agriculturist. It is of far more consequence to him that the moment he casts his eye upon the face of a country he can detect the presence or absence of peat—that none of the perplexities which beset the nature and origin of other superficial accumulations attach to this—that he can, at once, judge both of its source and of its agricultural capabilities. Though produced on a given spot, because rocks of a certain character exist there, yet its origin is always the same—its qualities more or less uniform,—the improvement of which is susceptible in some measure alike,—and the steps by which that improvement is to be effected, liable to variation, chiefly according as this or that ameliorating substance can be most readily obtained.

LECTURE XIII.

Exact chemical constitution of soils—their organic constituents—Analysis of soils—Composition of certain characteristic soils—Physical characters of soils.

In the two preceding lectures we have considered the general constitution and origin of soils, and their relation to the geological structure of the country in which they are found, and to the chemical composition of the rocks on which they rest. We have also discussed some of the causes of those remarkable differences which soils are known to present in their relations to practical agriculture. But a more intimate and precise acquaintance with the chemical constitution of soils is not unfrequently necessary to a complete understanding of the causes of these differences—of the exact effect which its chemical constitution has upon the fertility of a soil—and of the remedy which in any given circumstances ought to be applied.

Some persons have been led to expect too much from the chemical analysis of a soil, as if this alone were necessary at once to explain all its qualities, and to indicate a ready method of imparting to it every desirable quality,—while others have as far depreciated their worth, and have pronounced them in all cases to be *more curious than useful*.—[Boussingault, 'Annal. de Chim. et de Phys.' lxvii., p. 9.] The truth here, as on most other subjects, lies in the middle between these extreme opinions.

If you have followed me in the views I have endeavoured to press upon you in regard to the necessity of *inorganic* food to plants—which food can only be derived from the soil, and which must vary in kind and quantity with the species of crop to be raised,—you will at once perceive that the *rigorous* analysis of a soil may impart most valuable knowledge to the practical man in the form of useful suggestions for its improvement. It may indeed show that to apply the only available substances to the soil which are capable of remedying its defects, would involve an expense for which, in existing circumstances, the land could never give an equivalent return. Yet even in this latter case the results of analysis will not be without their value to the prudent man, since they will deter him from adding to his soil what he knows it already to contain, and will set him upon the search after some more economical source of those ingredients which are likely to benefit it most.

It will be proper, therefore, to turn our attention briefly to the consideration of the exact chemical constitution of soils.

§ 1. *Of the exact nature of the organic constituents of soils, and of the mode of separating them.*

We have already seen in Lecture XI., p. 229, that all soils contain a greater or less admixture of organic—chiefly vegetable—matter, the total amount of which may be very nearly determined by burning the *dried* soil at a red heat till all blackness disappears (p. 233). But this vegetable matter consists of several different chemical compounds, the nature and relative weights of which it is occasionally of consequence to be able to determine.

1°. *Humus.*—The general name of humus is given to the fine, brown light powder which imparts their richness to vegetable moulds and garden soils. It is formed from the gradual decomposition of vegetable matter, exists in all soils, forms the substance of peat, and consists of a mixture of several different compounds which are naturally produced during the decay of the different parts of plants. It is distinguished into *mild*, *sour*, and *coaly* humus.

The *mild* gives a brown colour to water, but does not render it sour, gives a dark brown solution when boiled with carbonate of soda, evolves ammonia when heated with caustic potash or soda or with slaked lime, and leaves an ash when burned which contains lime and magnesia. The *sour* gives, with water, a brown solution of a more or less sour taste, [or reddens vegetable blues—see page 45.] This variety is less favourable to vegetation than the former, and indicates a want of lime in the soil. The *coaly* humus gives little colour to water or to a hot solution of carbonate of soda, leaves an ash which contains little lime, occurs generally on the surface of very sandy soils, and is very unfruitful. It is greatly ameliorated by the addition of lime or wood ashes.

2°. *Humic acid.*—When a fertile soil or a piece of dry peat is boiled with a solution of the common carbonate of soda of the shops, a brown solution, more or less dark, is obtained, from which, when diluted muriatic acid (spirits of salt) is added till the liquid has a distinctly sour taste, brown flocks begin to fall. This brown flocky matter is *humic acid*.

3°. *Ulmic acid.*—If, instead of a solution of carbonate of soda, one of caustic ammonia, (the hartshorn of the shops,) be digested upon the soil or peat by a gentle heat, a more or less dark brown solution is obtained, which, on the addition of muriatic acid, gives brown flocks as before, but which now consists of *ulmic acid*.

These two acids combine with lime, magnesia, alumina, and oxide of iron, forming compounds (salts) which are respectively distinguished by the names of *humates* and *ulmates*. They probably both exist, ready formed, in the soil in variable proportions, and in combination with one or more of the earthy substances above mentioned—lime, alumina, &c. They are produced by the decay of vegetable matter in the soil, which decay is materially facilitated by the presence of one or other of these substances, and by lime especially—on the principle that the formation of acid compounds is in all such cases much promoted by the presence of a substance with which that acid may combine. They *predispose* organic substances to the formation of such acids, and consequently to the decomposition by which they are to be produced. These two acids consist respectively of

	Humic acid.	Ulmic acid.
Carbon	63	57
Hydrogen	6	$4\frac{3}{4}$
Oxygen	31	$38\frac{1}{4}$
	100	100

Some writers upon agriculture have supposed that these acids contribute very materially to the support of growing plants. But Liebig

has very properly objected to this opinion,* that they are so very sparingly soluble in water that we cannot suppose them to enter directly into the roots—even were all the water they absorb to be saturated with them—in such quantity as to contribute in a great degree to the organic matter contained in almost any crop.†

We have indeed seen reason to conclude on other grounds, that only a small, though a variable, proportion of the carbon of plants is derived from the soil, yet of this proportion a certain quantity may enter by the roots in the form of one or other of these acids, or of their earthy compounds. They are readily soluble in ammonia; and animal manures which give off this compound in the soil may therefore facilitate their entrance into the roots of those plants which are cultivated by the aid of such manures. They are also soluble in carbonate of potash and carbonate of soda, which are contained in wood ashes and in the ash of weeds and of soils which are pared and burned. When these substances, therefore, are applied to the land, they may combine with, and, among their other beneficial modes of action, may serve to introduce, these acids in larger quantity into the plant.

When exposed to the air, the humates and ulmates contained in the soil undergo decomposition, give off carbonic acid, and are changed into carbonates. The admission of air into the soil facilitates this decomposition, which is supposed to be continually going forward—and it is in the form of this gas that plants are considered by some to imbibe the largest portion of that carbon for which they are indebted to the soil.

4°. *Crenic and Aprocrenic acids.*—When soils are digested or washed with hot water, a quantity of organic matter is not unfrequently dissolved, which imparts to the water a brownish yellow colour. When the solution is evaporated to dryness, there remains besides the soluble saline substances of the soil, a variable portion of brown extractive looking matter also, which is a mixture of the two acids here named, with the ulmic and humic—all in combination with lime, alumina, and other bases. When this residue is dried at 230° F., the two latter acids, and their compounds, become insoluble, while the *crenates* and *apocrenates*, more especially the former, remain soluble in water, and may be separated by washing with this liquid.

These acids also are formed in the soil during the decay of vegetable matter. They are distinguished from the two previously described by containing nitrogen as an essential constituent, and by forming compounds with lime, &c., which are, for the most part, readily soluble in water. Hence they will both prove more nourishing to plants—in virtue of the nitrogen they contain—and in consequence of their solubility, will be able, where they exist, to enter more readily, and in greater abundance, into the roots than either the ulmic or the humic acid.

Owing to this solubility, also, they are more readily washed out of the soil by the rains, and hence are rarely present in any considerable quan-

* *Organic Chemistry applied to Agriculture*, first edition, pp. 11 and 12.

† Ulmic acid requires 2500 times its weight of water to dissolve it—ulmate of lime 2000 times, and ulmate of alumina 4200 times—but all are still less soluble after they have been perfectly dried, or exposed to the action of a hard winter's frost. The ulmates of potash, soda, and alumina, are all dissolved in water with considerable ease.

tity in specimens of soil which are submitted to analysis. They are frequently, however, met with in springs and in the drainings of the land. They have even been found in minute quantity in rain-water,* it is probable that they ascend into the air in very small proportion with the watery vapour that rises. This exhibits another form, therefore, in which the rains may minister to the growth of plants (see page 36).

Both acids form insoluble compounds with the peroxide of iron—and hence are found in combination with many of the ochrey deposits from ferruginous springs, and with the oxide of iron by which so many soils are coloured. The apocrenic acid has also a peculiar tendency to combine with alumina, with which it forms a compound insoluble in water, and in this state of combination it probably exists not unfrequently, especially in clayey soils.

When heated with newly slaked quick-lime these acids give off ammonia and carbonic acid. By the action of the air, and of lime in the soil, they are probably decomposed in a similar manner, though with much less rapidity.

5°. *Mudesous acid* is another dark brown acid substance, which is also produced naturally in the soil. It resembles the apocrenic, in having a strong tendency to combine with alumina. In union with this acid it is slowly washed out of the soil by the rains, or filters through it when the water can find an outlet beneath. This is seen to be the case in some of the caves on the Cornish coast, where the waters that trickle through from above have gradually deposited on their roof and sides a thick incrustation of *mudesite of alumina*.†

Besides these acids, it is known that the malic and the acetic (vinegar) are occasionally produced in the soil during the slow decay of vegetable matter of different kinds. It is probable that many other analogous compounds are likewise formed—which are more or less soluble in water, and more or less fitted to aid in the nourishment of plants. There is every reason to believe, indeed, that organic substances in the soil pass through many successive stages of decomposition, at each of which they assume new properties, and become more or less capable of aiding in the support of living races. The subject is difficult to investigate, because of the obstacles which lie in the way of exactly separating from each other the small quantities of the different organic compounds that occur mixed up together in the soil. But it seems quite clear, that while some agricultural chemists have erred in describing the ulmic and humic acids as the *immediate* source of a large portion of the carbon of plants, others have no less misstated—as I apprehend—the true course of nature, who deny any *direct* influence to these and other substances of vegetable origin, and limit their use in the soil to the supply of carbonic acid only, which, on their ultimate decomposition, they are capable of yielding to the roots. The resources of vegetable life are not so limited; but as the human stomach can, and does, on occasion, convert into nourishment many different compounds of the same elements,—so, no doubt, many of those organic compounds which are produced in the soil, or in fermenting manure during the decay of animal and vegetable

* Fürsten zu Salm-Horstmar. *Poggend. Annal.* liv., p. 254.

† Known to mineralogists under the name of *Pigotite*.

bodies,—when once admitted, in consequence of their solubility, into the circulating system of plants,—are converted into portions of their substance, and really do minister to their natural growth.

Separation of these Organic Constituents.—1°. When on washing with hot water a soil imparts a colour to the solution, the liquid must be filtered and evaporated, to perfect dryness. On treating with water what remains after the evaporation, the humic acid and humates remain insoluble, while the crenic and apocrenic acids are taken up by the water along with the soluble saline matter which the soil may have contained. By evaporating this second solution to perfect dryness, weighing the residue, and then heating it to dull redness in the air, the loss will indicate something more than the quantity of these acids present in the soil. By burning the dried insoluble matter, also, the quantity of humic acid present in it may in like manner be determined.

2°. After being washed with pure water, the soil is to be boiled with a solution of carbonate of soda, repeated once or twice as long as a brown solution, more or less dark, is obtained. Being filtered, and then rendered sour by muriatic acid, brown flocks fall, which being collected on the filter, perfectly dried and weighed, give the quantity of *humic acid* in the soil. As this dry humic acid generally contains some earthy matter, it is more correct to burn it, and to deduct the weight of the ash which may be left.

3°. The insoluble (coaly) humus still remains in the soil. On boiling it now in a solution of caustic potash for a length of time, and till a fresh solution ceases to become brown, the coaly humus is entirely dissolved—being converted according to Sprengel into humic acid. The addition of muriatic acid to this solution, till it has a sour taste, throws down the humic acid in the form of brown flocks, which may be collected, dried, and weighed as before.

4°. If there be any mudesite of alumina in the soil, it is also dissolved by the potash, but is not thrown down when the solution is rendered sour by muriatic acid. The entire weight of organic matter in the soil being therefore determined by burning it in the air, after being perfectly dried, the difference between this weight and the sum of those of the humic acid and insoluble humus will be the proportion of the other acids present. Thus, if, by burning in the air, the soil lose 6 per cent., and give 2 per cent. of humic acid, and 2 of insoluble humus, there remain 2 per cent. for other organic substances in the soil.

In general, it is considered sufficient to ascertain only the whole loss by burning, and the quantity taken up by carbonate of soda, the proportion of the other substances present being in most cases so small as to be capable of being precisely estimated by great precautions only.

§ 2. *On the exact chemical constitution of the earthy part of the soil.*

In reference to the general origin of soils—to their geological relations—and to the simplest mode of classifying them,—I have shown you that the earthy part of nearly all soils consists essentially of sand, clay, and lime (p. 230). But in reference to their chemical relations to the plants which grow, or may be made to grow, upon them, it is necessary, as you are now aware, to take a more refined and exact view of their

constitution. This will appear by referring to three important principles established in the preceding lectures.

1°. That the ash of plants generally contains a certain sensible proportion of ten or twelve different inorganic substances (pp. 216 to 221).

2°. That they can, in general, only derive these substances from the soil, which must, therefore, contain them (p. 181). And—

3°. That the fertility of a soil depends, among other circumstances, upon its ability to supply readily and in sufficient abundance all the inorganic substances which a given crop requires (p. 228.)

Now the quantity of some of these substances which is necessary to plants is so very small, that nothing but a refined analysis of a soil is capable, in many cases, of determining whether they are present in it or not—much less of explaining to what its peculiar defects or excellencies may be owing—what ought to be added to it in order to render it more productive—or why certain remarkable effects are produced upon it by the addition of mineral or animal manures.

Thus, for example, half a grain of gypsum in a pound of soil indicates the presence of nearly two cwt. in an acre, where the soil is a foot deep,—a quantity much greater than need be added to a soil in which gypsum is almost entirely wanting, in order to produce a remarkable luxuriance in the red clover crop. In 100 grains of the soil, this quantity of gypsum amounts only to seven-thousandths of a grain—($\frac{7}{1000}$, or 0·007 grs.)—a proportion which only a very carefully conducted analysis would be able to detect, and yet the detecting of which may alone be able to explain the unlike effects which are seen to follow the application of gypsum to different soils.

Again, the phosphoric acid is a no less necessary constituent of the soil than the sulphuric acid contained in gypsum. This acid is generally in combination either with lime, with oxide of iron, or with alumina—and, as it is much more difficult even to detect than the sulphuric acid, requires more care and skill to determine its quantity with any degree of accuracy,—and is generally present even in fertile soils in a still smaller proportion—it is obvious that safe and useful conclusions can be drawn only from such analyses as have been made rigorously, according to the best methods, and with the greatest attention to accuracy.

There are cases, no doubt, where a rough analysis may be of use, where the cause of peculiarity is at once so obvious that further research is unnecessary—as where mere washing with water dissolves out a noxious substance, such as sulphate of iron (green vitriol). But such cases are comparatively rare, and it more frequently happens, that the cause of the special qualities of a soil only begins to manifest itself when a carefully conducted analysis approaches to its close. I shall, therefore, briefly describe to you the methods to be adopted, in order to arrive at these more accurate experimental results. [As these methods of analysis involve considerable detail, I have transferred them to the Appendix.—*See Appendix, p.* 25.]

§3. *Of the exact chemical constitution of certain soils, and of the results to be deduced from them.*

But the importance of this attention to rigorous analysis will more clearly appear, if I exhibit to you the constitution of a few of the numerous soils analyzed by Sprengel, in connection with the agricultural qualities and capabilities by which they are severally distinguished.

The following analyses are selected from a much greater number made by Sprengel, and embodied in his work on soils, "Die Bodenkunde."

I.—FERTILE SOILS.

Soils are fertile which contain a sufficient supply of all the mineral constituents which the plants to be grown upon them are likely to require.

1°. *Pasture.*—The following numbers exhibit the constitution of the surface soil in three fertile alluvial districts of Hanover, where the land has been long in pasture.

	Soil near Osterbruch.	From the banks of the Weser, near Hoya.	near Weserbe.
Silica, Quartz, Sand, and Silicates.	84·510	71·849	83·318
Alumina	6·435	9·350	3·085
Oxides of Iron	2·395	5·410	5·840
Oxide of Manganese	0·450	0·925	0·620
Lime	0·740	0·987	0·720
Magnesia	0·525	0·245	0·120
Potash and Soda extracted by water	0·009	0·007	0·005
Phosphoric Acid	0·120	0·131	0·065
Sulphuric Acid	0·046	0·174	0·025
Chlorine in common Salt . .	0·006	0·002	0·006
Humic Acid	0·780	1·270	0·800
Insoluble Humus	2·995	7·550	4·126
Organic matters containing Nitrogen	0·960	2·000	1·220
Water	0·029	0·100	0·050
	100	100	100

These soils had all been long in pasture, the second is especially celebrated for fattening cattle when under grass. It will be observed that in none of them is any of the mineral ingredients wholly wanting, though in all the quantity of potash and soda capable of being extracted by water is very small. This is ascribed to the fact of their having been long in pasture, during which the supply of these substances is gradually withdrawn by the roots of the grasses. It is well known how, in our ordinary soils, grass is often renovated—how the mosses, especially, are destroyed—by a dressing of wood ashes, which owe their effect to the alkali they contain. In the above soils the gradual decomposition of the *silicates* would continue to supply a certain portion of alkaline matter for an indefinite period of time.

You will perceive that the soil which is the most celebrated for its *fattening* power, is also the richest in alumina, lime, phosphoric acid, sulphuric acid, and vegetable matter.

2°. *Arable.*—The following table exhibits the constitution of three soils, celebrated for yielding successive crops of corn for a long period without manure.

	1. From Nebtsein, near Olmutz, in Moravia.	2. From the banks of the Ohio, North America. Soil.	Subsoil.	3. From the polde, of Alt-Arenberg in Belgium.
Silica and fine Sand	77·209	87·143	94·261	64·517
Alumina	8·514	5·666	1·376	4·810
Oxides of Iron	6·592	2·220	2·336	8·316
Oxide of Magnesia	1·520	0·360	1·200	0·800
Lime	0·927	0·564	0·243	Carb of Lime 9·403
Magnesia	1·160	0·312	0·310	Carb. of Mag. 10·361
Potash chiefly combined with Silica	0·140	0·120	0·240	0·100
Soda, ditto	0·640	0·025		0·013
Phosphoric Acid combined with Lime and Oxide of Iron	0·651	0·060	trace	1·221
Sulphuric Acid in gypsum	0·011	0·027	0·034	0·009
Chlorine in common salt.	0·010	0·036	trace	0·003
Carbonic Acid united to the Lime	—	0.080	—	—
Humic Acid	0·978	1.304	—	0·447
Insoluble Humus	0·540	1.072	—	—
Organic substances containing Nitrogen	1·108	1·011	—	—
	100	100	100	100

Of these soils, the first had been cropped for 160 years successively, without either manure or naked fallow. The second was a virgin soil, celebrated for its fertility. The third had been unmanured for twelve years, during the last nine of which it had been cropped with beans—barley—potatoes—winter barley and red clover—clover—winter barley—wheat—oats—naked fallow.

Though the above soils differ considerably, as you see, in the proportions of some of the constituents, yet they all agree in this—that they are not destitute of any one of the mineral compounds, which plants necessarily require in sensible quantity. You will also observe how comparatively small a proportion of vegetable matter, less than half a per cent., is contained in the fertile Belgian soil—a fact to which I shall by-and-by recall your attention.

3°. *Soils which have a natural source of fertility.*—Some soils, which by their constitution are not fitted to exhibit any great degree of fertility, or for a very long period, are yet, by springs or otherwise, so constantly supplied with soluble saline, and other substances, as to enable them to yield a succession of crops, without manure, and without apparent deterioration. Such is the case with the following soil from near Rothen-

felde, in Osnabruck, which gives excellent crops, though manured only once in 10 or 12 years.

Silica and coarse Quartz Sand	86·200
Alumina	2·000
Oxides of Iron and a little Phosphoric Acid .	2·900
Oxide of Manganese	0·100
Carbonate and a little Phosphate of Lime .	4·160
Carbonate of Magnesia	0·520
Potash and Soda	0·035
Phosphoric Acid	0·020
Sulphuric Acid	0·021
Chlorine	0·010
Humic Acid	0·544
Insoluble Humus	3·370
Organic matter containing Nitrogen . . .	0·120
	100

You will see that, although in this soil all the inorganic substances are really present, yet the potash and soda, the phosphoric and sulphuric acids, and the chlorine, are not in such abundance as to justify us in expecting it to grow any long succession of crops, without exhibiting the usual evidences of exhaustion. But it lies on the side of a hill which contains layers of lime-stone and marl, through which the surface waters find their way. These waters afterwards rise into the soil of the field, impregnated with those various substances of which the soil is in want, and thus, by a natural manuring, keep up a constant supply for each succeeding crop.

This example is deserving of your particular attention, inasmuch as there are many soils, in climates such as ours, which are yearly refreshed from a similar source. Few spring waters rise to the surface which are not fitted to impart to the soil some valuable ingredient, and which, if employed for the purposes of irrigation, would not materially benefit those lands especially on which our pasture grasses grow. The same may also be said of the waters which are carried off in some places so copiously by drains. Whether these waters rise from beneath in springs, or, falling in rain, afterwards sink through the soil, they in either case carry into the brooks and rivers much soluble matter, which the plants would gladly extract from them. On sloping grounds it would be a praiseworthy economy to arrest these waters, and, before they escape, to employ them in irrigation.

The fact that nature thus on many spots brings up from beneath, or down from the higher grounds, continual accessions of new soluble matter to the soil, will serve to explain many apparent anomalies, and to account for the continued presence of certain substances in small quantity, although year by year portions of them are carried off the land in the crops that are reaped, while no return is made in the shape of artificial manure. It will also in some instances account for the fact that, after a hard cropping, prolonged until the soil has become exhausted, a few years' rest will completely re-invigorate it, and render it fit to yield

new returns of abundant corn. Other causes, as we shall hereafter see, generally operate in bringing about this kind of natural recovery, but there can be no question that in circumstances such as I have now adverted to, this recovery may be effected in a much shorter period of time.

4°. *Importance of depth and uniformity of soil.*—If the surface soil be of a fertile quality, ample returns will be sure from many cultivated crops. But where the subsoil is similar in composition to that of the surface—not only may the fertility of the land be considered as almost inexhaustible, but those crops also which send their roots far down will be able permanently to flourish in it. This fact is illustrated by the composition of the following soils from the neighbourhood of Brunswick:—

	1.		2.
	Soil.	Subsoil.	Subsoil.
Silica and fine Quartz Sand	94·724	97·340	90·035
Alumina	1·638	0·806	1·976
Oxides of Iron	1·960	1·126	5·815
Oxides of Manganese		0·075	0·240
Lime	1·028	0·296	0·022
Magnesia	trace	0·095	0·115
Potash and Soda	0·077	0·112	0·306
Phosphoric Acid	0·024	0·015	0·098
Sulphuric Acid	0·010	trace	1·399
Chlorine	0·027	trace	trace
Humic Acid	0·302	0·135	—
Insoluble Humus	0·210	—	—
	100	100	100

The first of these soils produced excellent crops of all deep-rooted plants—lucerne, sainfoin (esparsette), hemp, carrots, poppies, &c.—and with the aid of gypsum, red clover, and leguminous plants (vetches, peas, and beans), in great luxuriance. The former of these facts is explained by the great similarity in constitution which exists between the surface and the under soils. To deep-rooted plants also the magnesia, in which the surface is deficient, is capable of being supplied by the under soil. The effect of the gypsum is accounted for by the almost total absence of sulphuric acid in the subsoil, but which the application of gypsum has introduced into the upper soil.

The second soil was taken from a field in which sainfoin died regularly in the second or third year after it was planted. This was naturally attributed to something in the subsoil. And, by the analyses above given, it was found to contain much sulphuric acid in combination with oxide of iron, forming sulphate of iron (green vitriol). This salt being noxious to plants, began to act upon the crop of sainfoin as soon as the roots had gone so deep as to draw sufficient supplies from the subsoil, and it thus gradually poisoned them, so that they died out in two or three years.

II.—BARREN OR UNFRUITFUL SOILS.

Soils are unfruitful or altogether barren, either when they contain too little of one or more of the inorganic constituents of plants, or when some substance is present in them in such quantity as to become hurtful or poisonous to vegetation. The presence of sulphate of iron in the subsoil just described is an illustration of the latter fact. In what way the *deficiency* of certain substances really does affect the agricultural capabilities of the soil will appear from the following analyses :—

	1. Moor land soil, near Aurich, East Friesland.		2. Another soil from the same neighbourhood.	3. Sandy soil from Wettingen in Lüneburg.	4. Soil on the Muschelkalk, near Mühlhausen.
	Soil.	Subsoil.			
Silica and Quartz Sand	70·576	95·190	61 576	96·000	77·780
Alumina	1·050	2·520	0·450	0·500	9 490
Oxides of Iron	0·252	1·460	0·524	2·000	5·800
Oxide of Manganese	trace	0·048	trace	trace	0·105
Lime	do.	0·336	0·320	0·001	0·866
Magnesia	0·012	0·125	0·130	trace	0·728
Potash	trace	0·072	trace	do.	trace
Soda	do.	0·180	do.	do.	do.
Phosphoric Acid	do.	0·034	do.	do.	0·003
Sulphuric Acid	do.	0·020	do.	do.	trace
Carbonic Acid	—	—	—	—	0·200
Chlorine	trace	0·015	trace	trace	trace
Humic Acid	11·910	—	11·470	0·280	0·732
Insoluble Humus	16·200	—	26·530	1·299	0·200
Water	—	—	—	—	4·096
	100	100	100	100	100

Each of these analyses is deserving of attention.

1°. That the barrenness of the moor-land soils (1 and 2) is to be attributed to their deficiency in the numerous substances of which they contain only traces, may almost be said to be proved by the fact—one long recognised and acknowledged on many of our own moor-lands and peaty soils—that when dressed with a covering of the subsoil they become capable of successful cultivation. The analysis of the subsoil in the second column shows that it contains *all those mineral constituents in which the soil itself is deficient*—and to the effect of these, therefore, the improvement produced upon the soil by bringing it to the surface is altogether to be attributed.

2°. The sandy soil, No. 3, is evidently barren for the same reason as the moorland soils, 1 and 2. The soil No. 4 rests on lime-stone, and was mixed with 7 per cent. of lime-stone gravel, and contains a great number of the substances which plants require—but its unfruitfulness is to be ascribed to the want of potash and soda, of sulphuric acid and of chlorine. Wood ashes and a mixture of common salt with gypsum or sulphate of soda, would probably have remedied these defects.

3°. Among the fertile soils to which I recently directed your attention (p. 284) was one from Belgium, in which the proportion of organic matter was less than half a per cent. of its whole weight. In the above table, on the other hand, we have two nearly barren soils, containing

each 11 per cent. of humic acid, besides a much larger proportion of insoluble organic matter. It is obvious, therefore, that the fertility of a soil is not dependent upon its containing this or that proportion of vegetable matter, either in a soluble or an insoluble form. It is certainly true that many very fertile soils do contain a considerable quantity of organic matter, in a form in which it may readily yield nourishment to the roots of plants. Yet such soils are not fertile merely in consequence of the presence of this organic matter, as a source of *organic* food to the plant. It may be present, and yet the soils, like those above-mentioned, may remain barren. Where soils become fertile apparently by the long accumulation of such vegetable matter in the soil, it is not *merely* because of the increase of purely organic substances, such as the humic and ulmic acids, but, because, as I have already had occasion to mention to you, the decaying vegetable matter which produces them contains *also*, and yields to the soil, a considerable abundance of some of those inorganic substances which plants necessarily require. The organic matter is an indication of their presence in such soils. But they may be present without the organic matter. They may either be duly proportioned in the soil by nature—or they may be artificially mixed with it, and then this use of the organic matter may be dispensed with. It is of more importance to bear this in mind, because not only vegetable physiologists, but some zealous chemists also, have laid great stress upon the quantity of soluble and insoluble organic matter contained in a soil, and have been led to consider it as a safe index of the relative fertility of different soils.

The history of science shows, by many examples, that those men who adopt extreme views,—who attempt to explain all phenomena of a given kind, by reference to a single specific cause—have ever been of very great use in the advancement of *certain* knowledge. Their arguments, whether well or ill founded, lead to discussion, to further investigation, to the discovery of exceptional cases, and, finally, to the general adoption of modified views which recognise the action of each special cause in certain special cases, but all in subordination to some more general principle.

Thus, if some ascribe the fertility of the soil to the presence of the alkalies in great abundance, others to that of the phosphates, others to that of lime, others to that of alumina, and others, finally, to that of vegetable matter in a soluble state—all these extreme opinions are reconciled, and their partial truths recognised, in one general principle, that *a soil to be fertile must contain all the substances which the plant we desire to grow can only obtain from the soil, and in such abundance as readily to supply all its wants; while at the same time it must contain nothing hurtful to vegetable life.*

III.—SOILS CAPABLE OF IMPROVEMENT BY THE ADDITION OF MINERAL MATTER.

On the principle above stated depends in very many cases the mode of improving soils by the addition of mineral substances, as well as the method of explaining the remarkable effects occasionally produced by their mixture with the land. The following analyses will place this matter in a clearer light:—

	1. Soil near Padingbüttel, on the Weser.	2. Near Drakenburg, on the Weser.	3. Near Gandersheim, in Brunswick.	4. Near Brunswick.
Silica and Quartz Sand	93·720	92·014	90·221	95·698
Alumina	1·740	2·652	2·106	0·504
Oxide of Iron	2·060	3·192	3·951	2·496
Oxide of Manganese	0·320	0·480	0·960	trace
Lime	0·121	0·243	0·539	0·038
Magnesia	0·700	0·700	0·730	0·147
Potash (chiefly in combination with Silica)	0·062	0·125	0·066	0·090
Soda (do.)	0·109	0·026	0·010	
Phosphoric Acid	0·103	0 078	0·367	0·164
Sulphuric Acid	0·005	trace	trace	0·007
Chlorine in common Salt	0·050	trace	0·010	0·010
Humic Acid	0·890	0·340	0·900	0·626
Other Organic matter	0·120	0·150	0·140	0·220
	100	100	100	100

The first of these soils produces naturally *beautiful* red clover—the second produces *very bad* red clover. On comparing the constitution of the two soils, we see the second to be deficient in sulphuric acid and chlorine. A dressing of gypsum and common salt would supply these deficiencies, and render it capable of producing this kind of clover. The third soil is remarkable for growing luxuriant crops of pulse, when manured with gypsum. The almost total absence of sulphuric acid explains this effect. The fourth soil was greatly improved by soap-boiler's ash, which supplied it with lime, magnesia, manganese, and other substances.

I need not further multiply examples to show you how much real knowledge is to be derived from a rigidly accurate analysis, not only in regard to the agricultural capabilities of a soil, but also in regard to the natural and necessary food of plants, and to the manner in which mineral manures act in promoting and increasing their growth. The illustrations I have already presented will satisfy you—

1°. That a fertile soil must contain all the inorganic constituents which the plant requires, and none that are likely to do it an injury.

2°. That if the addition of a given manure to the soil render it more fertile—it is because the soil was defective in one or more of those substances which the manure contained.

3°. That if a given application to the land fail to improve it—of gypsum, of bone-dust, of common salt, for example—it is because enough of the substance applied is already present, or because something else is still wanting to render the previous additions available.

4°. That the result of extended experience in our country, that the clay soils are best for wheat, and sandy soils, such as that of Norfolk, for barley, is not to be considered as anything like a law of nature: setting aside the clay land for the special growth of wheat, and denying

to the sandy soils the power of yielding abundant crops of this kind of grain. Almost every district can present examples of well cultivated fields, where the contrary is proved—and the wheat crops which are yearly reaped from the sandy plains of Belgium, demonstrate it on a more extended scale.

Chemically speaking, a soil will produce any crop abundantly, provided it contain an ample supply of all that the crop we wish to raise may happen to require. But, in practice, soils which do not contain all these substances plentifully, are yet found to differ in their power of yielding plentiful returns to the husbandman. Such differences arise from the climate, the exposure, the colour, the fineness of the particles, the lightness or porosity of the soil—from the quantity of moisture it is capable of retaining, or from some other of its numerous physical properties. These physical properties, therefore, it is necessary shortly to consider.

§ 4. *Of the physical properties of soils.*

To the physical properties of soils was formerly ascribed a much more fundamental importance than we can now attach to them. Crome and Schübler regarded the fertility of a soil as entirely dependent upon its physical properties. Influenced by this opinion, the former published the results of an examination of numerous soils in the Prussian provinces, which are now possessed of no scientific interest; because they merely indicate the amount of clay, sand, and vegetable matter which these soils severally contained.* The latter completed a very elaborate examination of the physical properties of soils, which is very useful and instructive;† but the defective nature of which, in accounting for their agricultural capabilities, became evident to the author himself, when the more correct and scientific views of Sprengel, illustrated in the preceding section, afterwards became known to him. In giving, therefore, their due weight to the physical properties, we must not forget that in nature they are subordinate to the chemical constitution of soils. Plants *may* grow upon a soil, whatever its physical condition—if all the food they require be within their reach—while, however favourable the physical condition may be, nothing can vegetate in a healthy manner, if the soil be deficient in some necessary kind of food, or contain what is destructive to vegetable life.

Of the physical properties of soils the most important are their density, their power of absorbing and retaining water and air, their capillary action, their colour, and their consistence or adhesive power. There are one or two others, however, to which it will be necessary shortly to advert.

I.—MECHANICAL RELATIONS OF SOILS.

1°. *The density and absolute weight of a soil.*—Some soils are much heavier than others, not merely in the ordinary sense of heavy and light, as denoting clayey and sandy soils, but in reference to the absolute weight of equal bulks.

* Recorded in his *Grundsätze der Agricultur Chemie.*

† *Der Boden und seine verhältnisse zu den Gewächsen.*

Thus a cubic foot of dry

Siliceous or Calcareous Sand—weighs about .	110 lbs.
Half Sand and half Clay	95
Of common arable Land, from	80 to 90
Of pure agricultural Clay (page 221) . . .	75
Of garden Mould, richer in vegetable matter .	70
Of a peaty Soil, from	30 to 50

Sandy soils, therefore, are the heaviest. The weight diminishes with the increase of clay, and lessens still further as the quantity of vegetable matter augments.

In practice, the denser a soil is, the less injury will be done to the land by the passage of carts and the treading of cattle in the ordinary operations of husbandry. In a theoretical point of view it is of consequence to vegetation, chiefly in so far as, according to the experiments of Schübler, the denser soils retain their warmth for a longer period when the sun goes down, or a cold wind comes on. Thus a peaty soil will cool as much in an hour and a half as a pure clay in two, or a sand in three hours.

2°. *Of the state of division of the constituent parts of the soil.*—With the relative weight of different soils, their state of division is in some degree connected. Some soils consist of an admixture of exceedingly fine particles both of sand and clay—while in others, coarse sand, stones and gravels, largely predominate. There can be no doubt that the state of the soil in this respect has a material influence upon its productive character, and consequently upon its money value, since the labours of the husbandman in lands of a stiffer and more coherent nature are chiefly expended in bringing them into this more favourable powdery condition. In the description and examination of a soil, therefore, this property ought by no means to be passed lightly over—since it is one in regard to which a mere chemical analysis gives us little or no information.

In some parts of the country, the farmer diligently gathers the stones off his land, while in others the practice is condemned as hurtful to the arable crops. The latter fact is explained by supposing that these stones in winter afford shelter to the winter-corn, and in warmer seasons protect the ground in some degree from the drying winds, and retain beneath them a supply of moisture of which the neighbouring roots can readily avail themselves.

3°. *Firmness and adhesive power of soils.*—When soils dry in the air they cohere and become hard and stiff in a greater or less degree. Pure siliceous sands, alone, do not at all cohere when dry—while pure clays become hard and very difficult to pulverize. In proportion to the quantity of sand with which the latter are mixed, do their tenacity and hardness diminish. The difficulty of reducing clays to a fine powder in the open field, or of bringing them into a good tilth, may be overcome, therefore, by an admixture of sand or gravel, but there are few localities where the expense of such an operation does not present an insurmountable obstacle. Thorough draining, however, subsoil ploughing, and careful tillage, will gradually bring the most refractory soils of this character into a condition in which they can be more perfectly and more economically worked.

Soils also adhere to the plough in different degrees, and, therefore, present a more or less powerful obstruction to its passage. All soils present a greater resistance when *wet* than when *dry*, and all considerably more to a wooden than to an iron plough. A sandy soil when wet offers a resistance to the passage of agricultural implements, equal to about 4 lbs. to the square foot of the surface which passes through it—a fertile vegetable soil or rich garden mould about 6 lbs., and a clay from 8 to 25 lbs. to the square foot. These differences will naturally form no inconsiderable items in the calculations of the intelligent farmer when he estimates the cost of working, and the consequent rent he can afford to pay for this or that soil, otherwise equal in value.

II.—RELATIONS OF SOILS TO WATER.

1°. *Power of imbibing moisture from the air.*—When a portion of soil is dried carefully over boiling water, or in an oven, and is then spread out upon a sheet of paper in the open air, it will gradually drink in watery vapour from the atmosphere, and will thus increase in weight. In hot climates and in dry seasons this property is of great importance, restoring as it does, to the thirsty soil, and bringing within the reach of plants, a portion of the moisture which during the day they had so copiously exhaled.

Different soils possess this property in unequal degrees. During a night of 12 hours, and when the air is moist, according to Schübler, 1000 lbs. of a perfectly dry

Quartz Sand will gain	0 lbs.	Clay Loam . . .	25 lbs.
Calcareous Sand. .	2	Pure Agricultural Clay	27
Loamy Soil . .	21		

and peaty soils, or such as are rich in vegetable matter, a still larger quantity.

Sir Humphry Davy found this property to be possessed in the highest degree by the most fertile soils. Thus, when made perfectly dry, 1000 lbs. of a

Very fertile Soil from East Lothian gained in an hour	18 lbs.
Very fertile Soil from Somersetshire	16
Soil worth 45s. per acre from Mersea, in Essex . .	13
Sandy Soil worth 28s., from Essex	11
Coarse Sand worth only 15s.	8
Soil of Bagshot Heath	3*

Fertile soils, therefore, possess this property in a very considerable degree, and, though we cannot, by determining this property alone, infer with safety what the fertility of a soil is likely to prove—since peaty soils and very strong clays are still more absorbent of moisture, and since this property is only remotely connected with the special chemical constitution of a soil—yet among arable, sandy, and loamy lands, it certainly does, as Sir Humphry Davy states, afford *one* means of judging of their relative agricultural capabilities.

2°. *Power of containing or holding water.*—If water be poured drop by drop upon a piece of chalk or of pipe-clay, it will sink in and disappear, but if the dropping be continued, the pores of the earth will by de-

* Sir H. Davy's Works, vol. vii., p. 326.

grees become filled with water, and it will at length begin to drop out from the under part as it is added above. This property is exhibited in a certain degree by all soils. The rain falls and is drunk in, the dew also descends, and is thus taken possession of by the soil. But after much rain has fallen, the earth becomes saturated, and the rest either runs off from the surface or sinks through to the drains. This happens more speedily in some soils than in others. Thus from 106 lbs. of dry soil, water will begin to drop—if it be a

Quartz Sand, when it has absorbed	25 lbs.
Calcareous Sand	29
Loamy Soil	40
English Chalk	45—J.
Clay Loam	50
Pure Clay	70

but a dry peaty soil will absorb a very much larger proportion (Schübler), before it suffers any to escape. Useful arable soils are found to be capable of thus containing from 40 to 70 per cent. of their weight of water. If the quantity be less than this, the soils are said to be best adapted for pine plantations,—if greater, for laying down to grass.

In dry climates this power of holding water must render a soil more valuable, whereas in climates such as ours, where rains rather over-abound, a simple determination of this property will serve to indicate to the practical farmer on which of his fields it is most important to him, in reference to surface water, that the operation of draining should be first and most effectually performed. The more water the soil contains within its pores, the more it has to part with by subsequent evaporation; and, therefore, the colder it is likely to be. The presence of this water also excludes the air in a great degree, so that for these, as well as for other reasons, it is desirable to afford every facility for the speedy removal of the excess of water from such soils as absorb it, and are capable of containing it, in a very large proportion.

3°. *Power of retaining water when exposed to the air.*—Unless when rain or dew are falling, or when the air is perfectly saturated with moisture, watery vapour is constantly rising from the surface of the earth. The fields, after the heaviest rains and floods, gradually become dry, though this, as every farmer has observed, takes place in some of his fields with much greater rapidity than in others. Generally speaking, those soils which are capable of arresting and *containing* the largest portion of the rain that falls, *retain* it also with the greatest obstinacy, and take the longest time to dry. Thus a sand will become as dry in one hour as a pure clay in three, or a piece of peat in four hours. This, therefore, not only explains, and shows the correctness of, the well-known distinctions of *warm* and *cold* soils, but exhibits another strong argument in favour of a perfect drainage of stiff soils and of such as contain a large proportion of decaying vegetable matter.

4°. *Capillary power of the soil.*—When water is poured into the sole of a flower-pot, the soil gradually sucks it in and becomes moist even to the surface. The same takes place in the soil of the open fields. The water from beneath—that contained in the subsoil—is gradually sucked up to the surface. Where water is present in excess, this capillary action, as it is called, keeps the soil always moist and cold.

The tendency of the water to ascend, however, is not the same in all soils. In those which, like sandy soils and such as contain much vegetable matter, are open and porous, it probably ascends most freely, while stiff clays will transmit it with less rapidity. No precise experiments, however, have yet been made upon this subject, chiefly, I believe, because this property of the soil has not hitherto been considered of such importance as it really is, to the general vegetation of the globe. Let us attend a little to this point.

I have already drawn your attention to the fact, that the specimens of soil which are submitted to analysis generally contain very little saline matter, and yet that in a crop reaped from the same soil a very considerable proportion exists. This I have attributed to the action of the rains which dissolve out the soluble saline matter from the surface soil, and as they sink, carry it with them into the subsoil; or from sloping grounds, and during very heavy rains, partly wash it into the brooks. Hence from the proportion of soluble matter present at any one time in the surface soil, we cannot safely pronounce as to the quantity which the whole soil is capable of yielding to the crop that may be grown upon it. For when warm weather comes and the surface soil dries rapidly, then by capillary action the water rises from beneath, bringing with it the soluble substances that exist in the subsoil through which it ascends. Successive portions of this water evaporate from the surface, leaving their saline matter behind them. And as this ascent and evaporation go on as long as the dry weather continues, the saline matter accumulates about the roots of the plants so as to put within their reach an ample supply of every soluble substance which is not really defective in the soil. I believe that in sandy soils, and generally in all light soils, of which the particles are very fine, this capillary action is of great importance, and is intimately connected with their power of producing remunerating crops. They absorb the falling rains with great rapidity, and these carry down the soluble matters as they descend—so that when the soil becomes soaked, and the water begins to flow over its surface, the saline matter being already buried deep, is in little danger of being washed away. On the return of dry weather, the water re-ascends from beneath and again diffuses the soluble ingredients through the upper soil.

In climates such as ours, where rains and heavy dews frequently fall, and where the soil is seldom exposed for any long period to hot summer weather unaccompanied by rain, we rarely see the full effect of this capillary action of the soil. But in warm climates, where rain seldom or never falls, the ascent of water from beneath, where springs happen to exist in the subsoil, goes on without intermission. And as each new particle of water that ascends brings with it a particle, however small, of saline matter (for such waters are never pure), which it leaves behind when it rises into the air in the form of vapour, a crust, at first thin, but thickening as time goes on, is gradually formed on the surface of the soil. Such crusts are seen in the dry season—in India, in Egypt, and in many parts of Africa and America. In hot, protracted summers they may be seen on the surface of our own fields, but they disappear again with the first rains that fall. Not so where rains are unknown. And thus on the arid plains of Peru, and on extensive tracts in Africa, a deposit of saline matter, sometimes many feet in thickness, is met with on the surface of

wide plains, in the hollows of deep valleys, and on the bottoms of ancient lakes. Such an incrustation, probably so formed, is the bed of nitrate of soda in Peru, from which all our supplies of that salt are drawn—such are the deposits of carbonate of soda (urao) extracted from the soil in the South American State of Colombia.

5°. *Contraction of the soil on drying.*—Some soils in dry weather diminish very much in bulk, shrink in, and crack. Thus, after being soaked by rain, pure clay and peaty soils diminish in bulk about one-fifth when they are again made perfectly dry—while sand has the same bulk in either state. The more clay or vegetable matter, therefore, a soil contains, the more it swells and contracts in alternate wet and dry weather. This contraction in stiff clays can scarcely fail to be occasionally injurious to young roots from the pressure upon the tender fibres to which it must give rise, while in light and sandy soils the compression of the roots is nearly uniform in all weathers, and they are undisturbed in their natural tendency to throw out off-shoots in every direction. Hence another good quality of light soils, and a less obvious benefit which must necessarily result from rendering soils less tenacious by admixture or otherwise.

III.—RELATIONS OF THE SOIL TO THE ATMOSPHERE.

Power of absorbing oxygen and other gaseous substances from the air.—1°. The importance of the oxygen of the atmosphere, first to the germination of the seed, and afterwards to the growth of the plant, I have already sufficiently insisted upon. It is of consequence, therefore, that this oxygen should gain access to every part of the soil, and thus to all the roots of the plant. This access can be facilitated by artificially working the land, and thus rendering it more porous. But some soils, in whatever state they may be in this respect, have been found to absorb oxygen with more rapidity, and in larger quantity, than others. Thus clays absorb more oxygen than sandy soils, and vegetable moulds or peats more than clays. This difference depends in part upon the natural porosity of these different soils, and in part also upon the chemical constitution of each. If the clay contain iron or manganese in the state of first or *prot*-oxides, these will naturally absorb oxygen for the purpose of combining with it,—while the decaying vegetable matter will in like manner, in such as contain it largely, drink in much oxygen to aid their natural decomposition.

2°. Besides the gases, oxygen and nitrogen, of which the air principally consists, the soil absorbs also carbonic acid from the atmosphere, and portions of those various vapours,—whether of ammonia and other effluvia which rise from the earth, or of nitric acid formed in the air,—and these, in the opinion of some chemists, contribute very materially to its natural fertility. This, however, is very much a matter of conjecture, and no experiments have been made as to the relative capabilities of different soils thus to extract vegetable food from the surrounding air. One fact, however, seems to be clearly ascertained, that all soils, namely, absorb gaseous substances of every kind most easily and in the greatest abundance when they are in a moist state. The fall of rains, or the descent of dew, therefore, will favour this absorption in dry seasons, and it will also be greatest in those soils which have the power of most readily

extracting watery vapour from the air during the absence of the sun. Hence the influence of the dews and of gentle showers on the progress of vegetation, is not limited to the mere supply of water to the thirsty ground, and of those vapours which they bring with them as they descend to the earth, but is partly due also to the power which they impart to the moistened soil, of extracting for itself new supplies of gaseous matter from the surrounding atmosphere.

IV.—RELATIONS OF THE SOIL TO HEAT.

There are some of the relations of soils to heat, which have considerable influence upon their power of promoting vegetation. These are the rapidity with which they absorb heat from the air, the temperature they are capable of attaining under the direct action of the sun's rays, and the length of time during which they are able to retain this heat.

1°. *Power of absorbing heat.*—It is an important fact, in reference to the growth of plants, that during sunshine, when the sun's rays beat upon it, the earth acquires a much higher temperature than the surrounding air. This temperature very often amounts to 110°, and sometimes to nearly 150°, while the air in the shade is between 70° and 80° only. Thus the roots of plants are supplied with that amount of warmth which is most favourable to their rapid growth.

Dark-coloured—such as black and brownish red—soils absorb the heat of the sun most rapidly, and therefore become warm the soonest. They also attain a higher temperature—by a few degrees only, however (3° to 8°),—than soils of other colours, and thus, under the action of the same sun, will more rapidly promote vegetation. In climates, such as ours, where the presence of the sun is often wished for in vain in time of harvest, this property of the soil possesses a considerable economical value. In other parts of the world, where sunshine abounds, it becomes of less importance.

Every one will understand that the above differences are observed among such soils only as are exposed to the same sun under the same circumstances. Where the exposure or aspect of the soil is such as to give it the prolonged benefit of the sun's rays, or to shelter it from cold winds, it will prove more propitious to vegetation than many others less favourably situated, though darker in colour and more free from superfluous moisture.

2°. *Power of retaining heat.*—But soils differ more in their power of retaining the heat they have thus absorbed. You know that all hot bodies, when exposed to the air, gradually become cool. So do all soils; but a sandy soil will cool more slowly than a clay, and the latter than a soil which is rich in vegetable matter. The difference, according to Schübler, is so great, that a peaty soil cools as much in one hour as the same bulk of clay in two, or of sand in three hours. This may no doubt have considerable influence upon growing crops, inasmuch as, after the sun goes down, the sandy soil will be three hours in cooling, while the clays will cool to the same temperature in two, and rich vegetable mould in one hour. But on those soils which cool the soonest, dew will first begin to be deposited, and it is doubtful, where the soils are equally drained, whether, in summer weather, the greater proportion of dew deposited on the clays and vegetable moulds may not more than compensate to the

parched soil—for the less prolonged duration of the elevated temperature derived from the action of the sun's rays. It is also to be remembered, that vegetable soils at least absorb the sun's heat more rapidly than the lighter coloured sandy soils, and thus the plants which grow in the former, which is sooner heated, may in reality be exposed to the highest influence of the sun's warmth—for at least as long a period as those which are planted in the latter.

The only power we possess over these relations of soils to heat, appears to be, that by top-dressing with charcoal, with soot, or with dark-coloured composts, we may render it more capable of rapidly absorbing the sun's heat, and by admixture with sand, more capable of retaining the heat which it has thus obtained.

Such are the most important of the physical properties of soils. Over some of them, the skilful farmer possesses a ready control. He can drain his land, and thus render it cheaper to work and more easy to reduce to a fine powder. He can plough, subsoil, and otherwise work it well, and thus can make it more open and porous, more accessible both to air and water. When it is light and peaty, he can lay heavy matter over it—clay, and sand, and lime-stone rubble—and can thus increase its density. He can darken its colour in some localities with peat composts, and can thus make it more absorbent of heat and moisture, as well as more retentive of the rain that falls. But here his power ends, and how far any of the changes within his power can be *prudently* attempted will depend upon the expense which, in any given locality, the operation would involve. And even after he has done all which mere mechanical skill can suggest, the soil may still disappoint his hopes, and refuse to yield him remunerating crops of corn.

"A soil," says Sprengel, "is often neither too heavy nor too light, neither too wet nor too dry, neither too cold nor too warm, neither too fine nor too coarse;—lies neither too high nor too low, is situated in a propitious climate, is found to consist of a well-proportioned mixture of clayey and sandy particles, contains an average quantity of vegetable matter, and has the benefit of a warm aspect and favouring slope."—[*Bodenkunde*, p. 203.] It has all the advantages, in short, which physical condition and climate can give it, and yet it is unproductive. And why? Because, answers chemical analysis, it is destitute of certain mineral constituents which plants require for their daily food. The physical properties, therefore, are only accessory to the chemical constitution. They bring into favourable circumstances, and thus give free scope to the operation, upon the seeds and roots of plants, of those chemical substances which Nature has kindly placed in most of our soils, or by the lessons of daily experience is teaching the skilful labourer in her fields to supply by art.

And yet the study of the physical properties of soils is not without its use, even in a theoretical point of view. It shows both the use of the fundamental admixture of sand, clay, and vegetable matter, of which our soils consist, and for what special end all the mechanical labours of the husbandman are undertaken, and why they are so necessary. Plants

must be firmly fixed, therefore the soil must have a certain consistency, —their roots must find a ready passage in every direction; therefore the soils must be somewhat loose and open. Except for these purposes, we see little *immediate* use for the sand and alumina which form so much of the substance of soils—till we come to study their physical properties. The siliceous sand is insoluble, and the alumina exists in plants in very minute quantity only, while during the progress of natural vegetation, the proportion of vegetable matter in the soil actually increases. The *immediate* agency, therefore, of these substances is not chemical but physical.

The alumina of the clays is of immediate use in absorbing and retaining both water and air for the use of the roots—while the vegetable matter is advantageous in reference to the same ends, as well as to the power of absorbing quickly and largely the warmth of the sun's rays. The soil, in short, in reference to vegetation, performs the four following distinct and separate, but each of them important and necessary, functions:—

1°. It upholds and sustains the plant, affording it a sure and safe anchorage.

2°. It absorbs water, air, and heat, to promote its growth

These are its mechanical and physical functions.

3°. It contains and supplies to the plant both organic and inorganic food as its wants require; and

4°. It is a workshop in which, by the aid of air and moisture, chemical changes are continually going on; by which changes these several kinds of food are prepared for admission into the living roots.

These are its chemical functions.

All the operations of the husbandman are intended to aid the soil in the performance of one or other of these functions. To the most important of these operations—the methods adopted by the practical farmer for improving the soil—it is my intention, in the following division of these Lectures, briefly to direct your attention.